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ULTRASONICS. VOLUME I - BASIC PRINCIPLES

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Ultrasonics, Vol. I - Basic Principle
CR 61209

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PREFACE

~~Programmed Instruction Handbook~~ - Ultrasonic T~~esting~~ (~~5330-1~~3, Vols. I-III) is home study material for familiarization and orientation on Nondestructive Testing. This material was planned and prepared for use with formal Nondestructive Testing courses. A~~lthough these courses are not scheduled at this~~ time the material will be a valuable aid for familiarization with the basics of Nondestructive Testing. ~~When used as pre-requisite material, it will help standardize the level~~ of knowledge and reduce class-room ~~lecture time to a minimum~~. The handbook has been prepared in a self-study format including self-examination questions.

It is intended that ~~handbook 5330.9,~~ Introduction to Nondestructive Testing, be completed prior to reading other ~~Programmed~~ Instruction ~~Hand~~books of the Nondestructive Testing series. The material presented in these documents will provide much of the knowledge required to enable ~~each~~ person to perform his Nondestructive Testing job effectively. ~~However~~, to master this knowledge considerable personal effort is required.

This Nondestructive Testing material is part of a large program to create an awareness of the high reliability requirements of the expanding space program. Highly complex hardware for operational research and development missions in the hazardous and, as yet, largely unknown environment of space makes it mandatory that quality and reliability be developed to levels heretofore unknown. The failure of a single article or component on a single mission may involve the loss of equipment valued at many millions of dollars, not to mention possible loss of lives, and the loss of valuable time in our space timetable.

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A major share of the responsibility for assuring such high levels of reliability, lies with NASA, other Government agencies, and contractor Nondestructive Testing personnel. These are the people who conduct or monitor the tests that ultimately confirm or reject each piece of hardware before it is committed to its mission. There is no room for error -- no chance for reexamination. The decision must be right -- unquestionably -- the first time. This handbook is one step toward that goal.

General technical questions concerning this publication should be referred to the George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory, Huntsville, Alabama 35812.

The recipient of this handbook is encouraged to submit recommendations for updating and comments for correction of errors in this initial compilation to George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory (R-QUAL-OT), Huntsville, Alabama 35812.

ACKNOWLEDGMENTS

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Aerojet-General Corp.; Automation Industries, Inc., Sperry Products Division; AVCO Corporation; The Boeing Company; Branson Instruments, Inc.; The Budd Co., Instruments Division; Douglas Aircraft Co., Inc.; General Electric Co.; Grumman Aircraft; Dr's Joseph & Herbert Krautkramer; Lockheed Aircraft Corp.; Magnaflux Corp.; The Martin Co. (Denver); McDonnell Aircraft Corp.; North American Aviation, Inc.; Pacific Northwest Laboratories, Battelle Memorial Institute; Pioneer Industries, Division of Almar-York Company, Inc. Rohr Corporation; Southwest Research Institute; St. Louis Testing Laboratories, Inc.; Uresco, Inc.; William C. Hitt; X-Ray Products Corp.

Our thanks is also extended to the many individuals who assisted in the testing of the materials to validate the teaching effectiveness. Their patience and comments contributed greatly to the successful completion of the handbook.

INTRODUCTION

Men have for centuries tested the soundness or quality of materials by striking them with some form of blunt instrument and then listening for a tonal difference which would denote a discontinuity. This form of testing is considered as the forerunner of present day ultrasonic testing.

Ultrasonics has become of great importance in recent years, its unique properties having been applied to industry, signaling, medicine, and many other fields. Research goes back many years; however, it was not until the 1930's that the possibility of using ultrasonic energy for nondestructive testing was recognized. Investigators in Germany, and to some extent Russia, developed ultrasonic testing methods which could determine gross discontinuities. These methods, however, had certain limitations, chief of which was the fact that both the front and back surfaces of the material had to be accessible. Attempts to find a method requiring access to only one surface were unsuccessful until the mid 1940's. At that time, F. A. Firestone, in this country, invented an instrument which used pulsed ultrasonic energy to obtain reflections from minute discontinuities. During the same period, D. O. Sproule in England independently developed other successful test devices. These first instruments were, for the most part, considered laboratory equipment and were used mostly for metallurgical research. In recent years, advances in instrumentation and electronic technology have supplied the necessary tools that have made possible the development of ultrasonic testing as we know it today. This is to say, a fast, reliable, quality assurance inspection device.

Regardless of your present level of knowledge on the subject of ultrasonic testing, this series of handbooks is intended to give you a sound basis of theoretical and practical knowledge on which to continue your training as ultrasonic testers. As a prerequisite to this handbook, you should complete 5330.9, Programmed Instruction Handbook - Introduction to Nondestructive Testing.

Following is a brief account of the contents of each volume:

Volume I - BASIC PRINCIPLES

To properly understand ultrasonic testing, a basic knowledge of ultrasonics and its respective terminology is the first essential. Volume I is devoted to teaching the basic theory and principles of ultrasonics. It introduces the reader to the various test systems, methods, and techniques used in ultrasonic testing and discusses the various types of displays. Brief coverage is also given on the effects of material geometry and grain structure, and how various types of discontinuities and their orientation affect ultrasonic sound.

Volume II - EQUIPMENT

The purpose of Volume II is to describe the various types of test equipment and accessories used in ultrasonic testing. In the five chapters of this volume, you will find: discussions on the many types of transducers and couplants used; the use and purposes of reference blocks; and a description of typical pulse-echo/through transmission equipment and their controls. Resonance equipment and recorders are also discussed. It is intended upon completion of this volume, that you be well grounded in your knowledge of ultrasonic test equipment and how it functions.

Volume III - APPLICATIONS

Volume III teaches the procedures to be followed in the selection of test equipment, methods, and techniques. It discusses the advantages and limitations of different test methods and techniques, and the conditions governing the selection of equipment, transducers, test frequencies, and couplants. You are taught how to "standardize" the equipment and inspect different materials, e.g., plate, forgings, and castings using both the contact and immersion test methods. Several specialized techniques are taught, e.g., the inspection of weldments, piping and tubing. And finally you are briefed on the use of resonance testing in thickness measuring, corrosion inspection, and locating gross discontinuities, e.g., delaminations and lack of bond.

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INSTRUCTIONS

The pages in this book should not be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page -

- Turn to the next page
- Turn to page 3-15
- Return to page 3-10

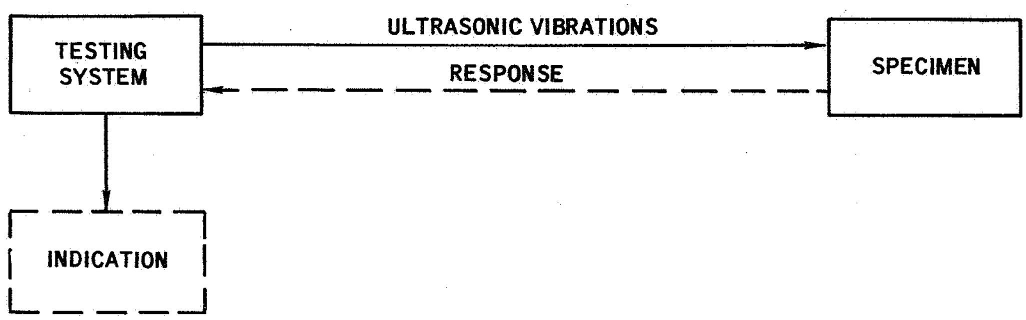
On many pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is correct and turn to the indicated page. That page will contain further instructions.

As you progress through the book, ignore the <u>backs</u> of the pages, THEY ARE PRINTED UPSIDE DOWN. You will be instructed when to turn the book around and read the upside down printed pages.

As you will soon see, it's very simple - just follow instructions

Turn to the next page.

Our study of ultrasonic testing begins with basic ultrasonic concepts. Let's start by realizing that ultrasonic testing is another form of nondestructive testing. This means that we have a typical nondestructive testing system.



Basically in ultrasonic testing we inject ultrasonic vibrations into a specimen. The specimen then modifies or changes these vibrations in some manner. The resulting change is detected by the testing system and, through an indication, we learn something about the specimen. As inspectors, our job is to properly apply the system to the specimen and interpret the results through the indications obtained.

You probably already have a feel for what an ultrasonic vibration is; however, we will define it in a moment. Right now, let's just keep in mind that it is used to learn something about a specimen.

Turn to page 1-2.

Visualize that we have a testing system and something called "ultrasonic vibrations" which we apply to a specimen. No recognizable response can be obtained from the testing system. This means...

the specimen is all right .... Page 1-3

the specimen does not adapt to ultrasonic testing .... Page 1-4

From page 1-2

You're wrong when you say the specimen is all right. Recall that we were applying something called "ultrasonic vibrations" to a specimen and did not obtain a recognizable response.

Since no recognizable response was obtained, we frankly do not know anything about the specimen. To learn something about the specimen, we need a response or reaction that we can interpret. The response will change as the specimen's properties change. Keep in mind the fact that the selection of a testing system is partly determined by the ability of the specimen to respond or react. That's why the correct answer to the question is the statement that the specimen does not adapt to ultrasonic testing.

Turn to page 1-4.

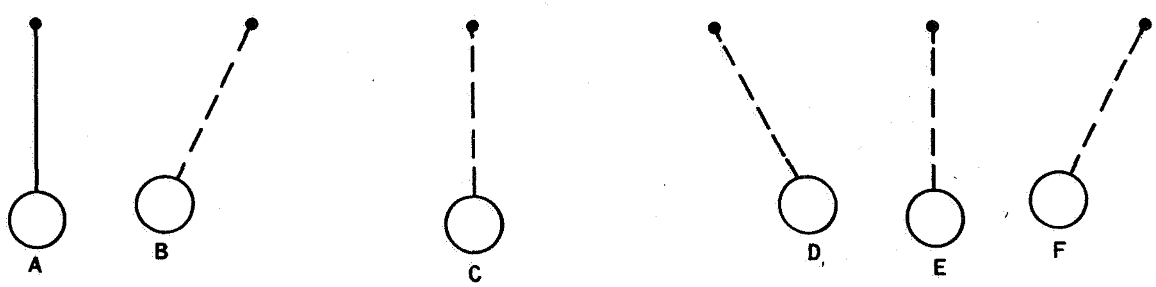
From page 1-2

Correct. Since no recognizable response indication was obtained, it's reasonable to say that the specimen does not adapt to ultrasonic testing. To learn something about a specimen, we need a response or reaction from the specimen that we can use. We didn't have the response or reaction; therefore, we can't learn anything about the specimen. Another form of nondestructive testing should be used in this case.

A moment ago you learned that in ultrasonic testing we use something called "ultrasonic vibrations". Of course you know what a vibration is. If we touch a radio or television set while it is operating, we get a sensation in our fingers. This means we have received energy (a vibration). We realize that the radio or television cabinet is vibrating and this is caused by the speaker.

For our purposes, we need to recognize two facts about a vibration: (1) a vibration is a back and forth movement and (2) a vibration is energy in motion.

Shown below is a ball suspended from a string (point A).



If we raise the ball (point B) and release it, the ball will swing through an arc (points C, D, E, and F). Note that we first gave energy to the ball by raising the ball (point B). The ball first moved in one direction and then in the opposite direction following the same path.

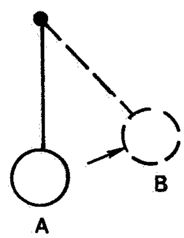
Is the following statement true or false? A vibration is energy moving back and forth.

True . . . . Page 1-5

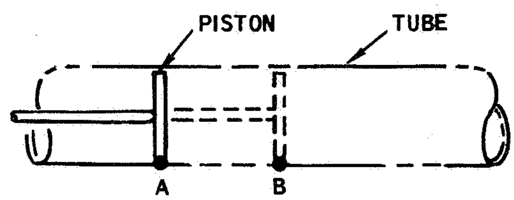
False . . . . Page 1-6

Fine! You recognized that a vibration is energy moving back and forth.

When a ball at rest is raised to a new position, we say the ball has been displaced (view A, below). And the distance the ball moves from its rest position is called the "displacement." This term also applies when the ball is released and swings to a new position in the opposite direction. As the ball swings back and forth, we can say that the ball is being displaced in both directions from the center rest position of the ball.

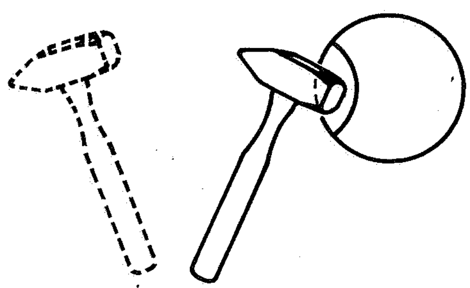


VIEW A



VIEW B

The term "displacement" can also be applied to a piston which moves back and forth within a tube (view B, above). For example, we can say that the piston has been displaced from position A to position B. And isn't it true that if we move the piston back and forth we can call this a vibration? Of course.



Visualize hitting the surface of a rubber ball with a hammer. The surface under the hammer moves inward and then returns to its normal position. Would you call the distance the surface moved inward from the normal surface position a displacement?

No . . . . Page 1-7

Yes . . . . Page 1-8

You have missed a concept when you say the statement "a vibration is energy moving back and forth" is false. The statement is true.

In our example, the ball was initially at rest. It did not have any energy. When we raised the ball, we gave it energy. Now, can't we say this energy is carried by the ball as it moves back and forth? Certainly. A vibration can be defined as energy moving back and forth.

Turn to page 1-5.

You said "no" and the correct answer is "yes." You were asked "Would you call the distance the surface moved inward from the normal surface position a displacement?"

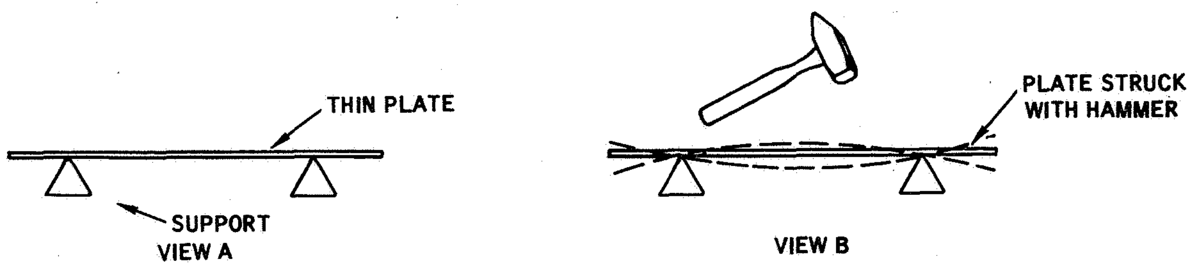
Recall that we learned that the distance something moves from a rest position (normal position) is called a displacement. The ball was one example; the piston was a second example. The surface of the rubber ball is a third example. The rubber ball's surface has a normal rest position. If we depress the surface, the surface moves inward and will return to its rest position if we remove our finger. The distance the surface moves inward is the displacement of the surface. The ball on the string, the piston in the tube, and the surface of the rubber ball all illustrate the concept of displacement.

Turn to page 1-8.

From page 1-5

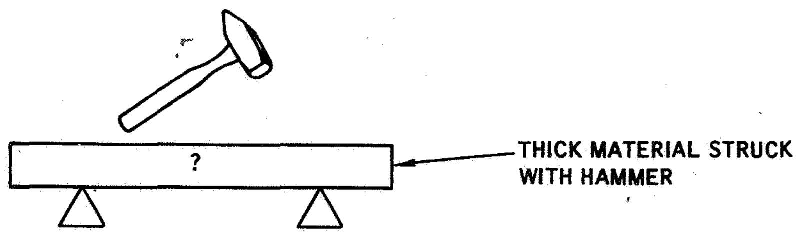
Correct again! You recognized that a surface depressed from a normal position is called a displacement. The swinging ball, the piston in the tube, and the depression of the rubber ball's surface all represent forms of displacement.

In ultrasonic testing, it is important to realize that the concept of displacement also applies to solid materials.



View A illustrates a thin plate positioned on supports and in a rest position. View B illustrates the plate vibrating after being struck by a hammer. Note in view B that we have two things: (1) vibration and (2) displacement.

Now consider the condition of a thick material which has been struck by a hammer.



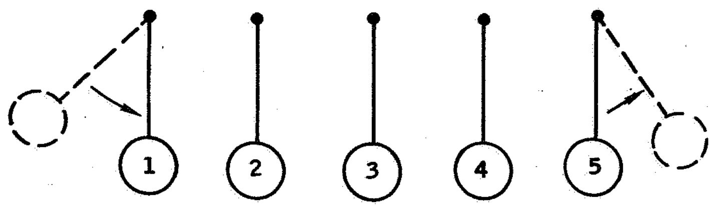
If we feel the material, we can sense the vibrations from the hammer blow. We can say...

the material has been displaced . . . . Page 1-9

the material has not been displaced . . . . Page 1-10

Certainly true. The material has been displaced.

Since ultrasonic testing is performed on solid materials, let's get a feel for what happens within the material. Vibrations pass through a solid material as a succession of particle displacements. To understand this idea, visualize that the material consists of a row of balls ... let's call them particles ... suspended as shown below.



If we displace particle 1 to the left and then release it, the energy we give particle 1 is transmitted through the series of particles 2 through 4 and finally affects particle 5. Particle 5 will then reverse the action and transmit the energy through the row of particles back to particle 1. Note that we have had a succession of particle displacements and energy has been transmitted through the row of particles. Also note that we have a back and forth action which we have defined as a vibration.

The structure of a material is actually small particles (atoms or groups of atoms). These particles have normal positions...let's call them rest positions...and can be displaced from these positions. The particles will also return to the rest positions. Recall that a rubber ball can be squeezed and will return to its original shape. The same is true for a solid material or even given areas within the material.

Is the following statement true or false? Energy is transmitted through a solid material by a series of small material displacements within the material.

False .... Page 1-11

True .... Page 1-12

You're wrong when you say that the material has not been displaced. True, you can't see the displacement as you could in the example of the thin plate vibrating. However, a solid material does have a displacement as well as a vibration.

You have learned that a vibration has a displacement and you know that vibrations exist in solid materials (recall the radio vibration example). If you have vibrations, you also have displacements.

Turn to page 1-9.

From page 1-9

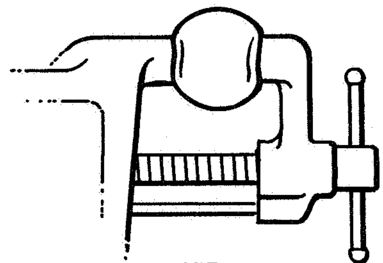
You're answer "False" is not correct. The statement "Energy is transmitted through a solid material by a series of small material displacements within the material" is true.

Look at it this way. You strike a thin plate with a hammer. Your energy is now in the plate. The plate vibrates and moves (displacement). Now let's use a thicker plate. Again you strike the plate. Again the plate vibrates but you can't see it move. You know it is vibrating and you can feel this vibration by placing your finger on the opposite side of the plate. In fact, if you used a glass of water on the plate, you could see the water move. And that's a displacement too.

We started with a displacement (a blow with a hammer) and we ended with a displacement (water moving in a glass). To get this, we must have had displacements within the material. That's why we say energy is transmitted through a solid material by a series of small material displacements within the material.

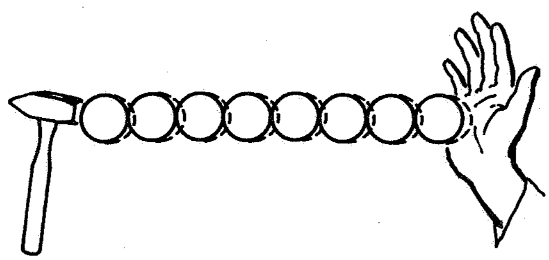
Turn to page 1-12.

Your answer "true" is correct. A series of small material displacements within the test material (specimen) is the way energy is transmitted through the specimen.



VIEW A

Now consider what we mean when we say a small material displacement. View A shows a steel ball placed in a vise. If we slightly tighten the vise, and measure the diameter of the ball, we find a change in dimension. The ball's compressed. Of course, if we measure across other diameters of the ball, we also find the ball is expanded. The ball is compressed in one area and is expanded in another area. And, if we remove the ball from the vise, we find that the ball returns to its original dimensions. From this, we get the idea that even a solid material is elastic - it contracts and expands - and returns to its original shape. Note that we have another form of displacement in this contraction and expansion of a ball.



VIEW B

View B illustrates the action of striking a solid material with a hammer and feeling the vibration. Visualize that the "balls" are packed so that they can't expand vertically; therefore, the expansion must be in the line of direction of the blow of the hammer

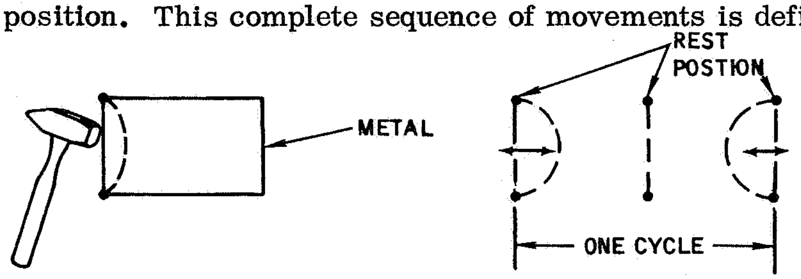
Select the best answer to the following statement. The transmission of ultrasonic vibrations through a material is...

related to the elastic property of the material. . . . . Page 1-13

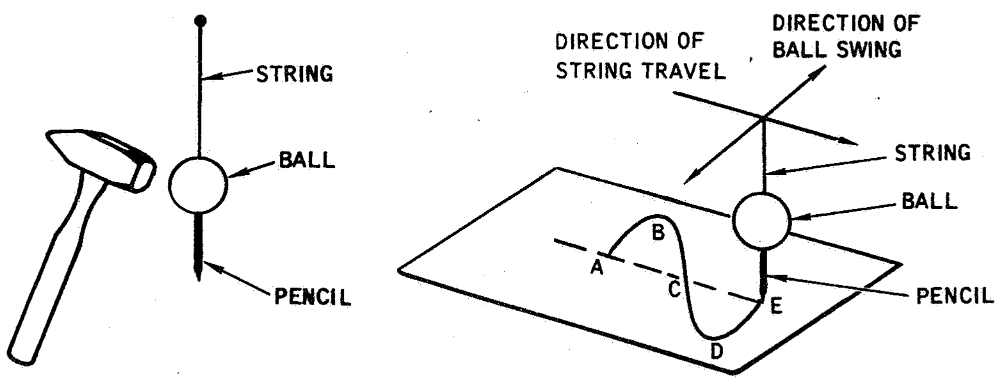
not related to the elastic property of the material . . . . Page 1-14

Correct again! You're doing fine. The transmission of ultrasonic vibrations through a material is related to the elastic property of the material. And it is this elastic property which permits energy to move through a material.

By now, you probably realize that a back and forth movement (vibration) has a better name. We call it a "cycle." If we tap a metal surface, the surface moves inward. The distance the surface moves inward is called the displacement. Since metal is elastic, the surface will move back to its original (rest) position. While we can't see it, the surface will also move through the original position and move to a maximum distance in the opposite direction. (Recall the example of the thin plate.) This new maximum distance is also called a displacement. And finally, the surface returns to its center or rest position. This complete sequence of movements is defined as a cycle.



Note that we have two displacements, first in one direction, and then in the opposite direction. Recall that a displacement is one movement from the rest position to a maximum distance in one direction.



Visualize that we have a ball on the end of a string and a pencil extending from the ball. We tap the ball to one side and move the top of the string horizontally to a surface. And the pencil swings back and forth making the curve shown above. This curve represents...

one cycle. . . . . Page 1-15

one displacement. . . . . Page 1-16

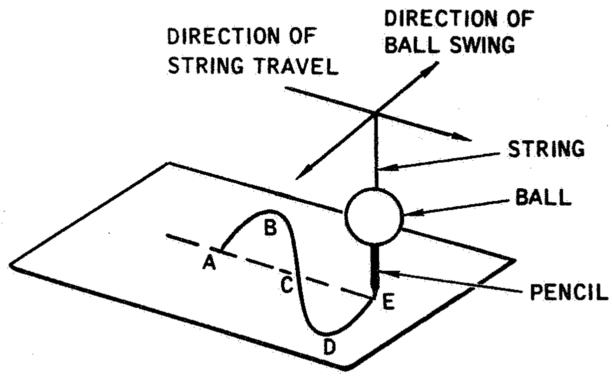
Apparently, you don't believe that the transmission of ultrasonic vibrations through a material is related to the elastic property of the material. You're incorrect.

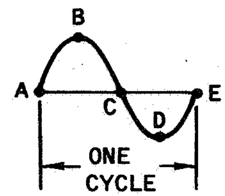
The fact that a material is elastic is the basis for the transmission of vibrations through a solid material. If we tap a material with a hammer, we momentarily depress the material's surface. The surface then returns to its original position. That makes it elastic. If we touch the opposite side of the material, we get a slight "push" from the material. We get displaced, don't we? Yes.

Between the two surfaces, something happens to transmit the blow of the hammer through the material. That something is the contraction and expansion of small material areas within the material. Such action is the elastic property of the material. And it is this elastic property that provides the means of transmitting vibrations through the material.

Turn to page 1-13.

Good! You have the concept. Two displacements make a cycle.





Now that you have the concept of a cycle, let's pick up the terms "period" and "frequency". The time required for something to move through one complete cycle is called the period. For example, if the swinging ball moves over the path ABCDE in one second, we say the period of the cycle is one second.

Naturally, you realize that the ball keeps swinging so that the cycle is repeated several times. The number of complete cycles in a given period of time is called the frequency. Normally, the unit of time measurement is the second; thus, we get the concept of cycles per second (cps). (It should be noted at this time that the term Hertz (abbreviated Hz) is now the universally accepted designation for the measure of frequency in place of cycles per second (cps). However, to avoid possible confusion by using the newer term, the more common phrase cycles per second (cps) is used in this handbook when referring to the measure of frequency.)

If the ball swings through three complete cycles in one second, we say the frequency is 3 cps (cycles per second). Note the relationship between period and frequency. For example, if the ball completes 100 cycles in one second, the frequency is 100 cps. The period is 1/100 of a second. Or we can say the period $= \frac{1}{\text{frequency}}$. Thus to get the period, you simply divide the frequency into the value one. That gives you the time for one cycle.

A record player generates an electrical signal by moving a needle back and forth in a groove in the record. The number of times the needle moves back and forth in one second is called...

the period . . . . .Page 1-17
the frequency. . . . . .Page 1-18

Incorrect. You have mixed the concept of displacement with the concept of the cycle. The curve represents <u>one cycle</u>, not one displacement (your answer).

A cycle is one complete movement in both directions from a center (rest) position. This means there are two displacements. A displacement is defined as a maximum movement from the center position in one direction. Note that a cycle moves in both directions from the center. Two displacements equal one cycle.

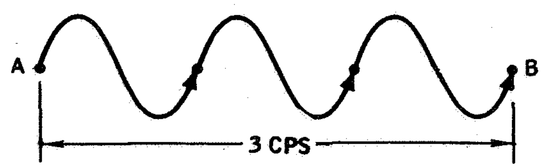
Turn to page 1-15.

You missed the concept. The number of times the needle moves back and forth in one second is called the frequency, not the period (your answer).

The period is the time required to make one complete cycle (one back and forth movement). The needle is moving back and forth many times in one second. The number of times it moves through a complete back and forth movement is the frequency.

Return to page 1-15, read the page, and try the question again.

Right. The number of times the needle moves back and forth (one cycle) in one second is called the frequency.



The above illustration represents a record player needle moving back and forth in a groove. The distance from A to B denotes the needle movement that takes place in one second. From this we can say the period of the cycle is...

1/3 of a second . . . . Page 1-19

3 seconds . . . . Page 1-20

[redacted])

Fine! You have the idea of the period. The answer "1/3 of a second" is correct. Period $= \frac{1}{\text{frequency}}$. The frequency was 3 cps (cycles per second); therefore, the period = 1/3 cps or 1/3 of a second.

<u>SUMMARY</u>: So far you have learned that...

- A vibration is energy moving back and forth.
- The distance something moves from a center position is called a displacement.
- Energy is transmitted through a solid material by a series of small material displacements within the material.
- The transmission of ultrasonic vibrations through a material is related to the elastic property of the material.
- One complete back and forth movement is a cycle.
- A cycle has two displacements; one in each direction from the center position.
- The number of cycles something passes through in one second is called the frequency.
- The time required to pass through one complete cycle is called the period.
- The period $= \frac{1}{\text{frequency}}$.

Turn to page 1-21.

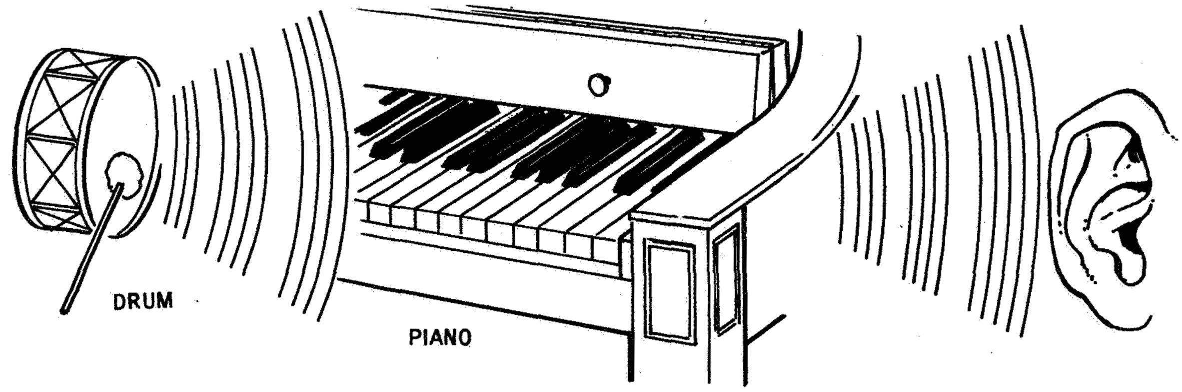
You are not correct. You said the period of the 3 cps (cycles per second) movement was 3 seconds. This is not true. The period is 1/3 of a second.

Recall that the period = $\frac{1}{\text{frequency}}$. Since the frequency is 3 cycles per second, the period is 1/3 of a second. Keep in mind that the period is the time required to pass through one complete cycle. Also recall that the frequency is the number of times something happens in one second; therefore, the answer 3 seconds doesn't make sense. The abbreviation cps means cycles per second.

Turn to page 1-19.

From page 1-19

One complete back and forth movement is a cycle. Such a movement can be generated in a number of ways.



For example, if you strike a drum, the top surface moves back and forth. Or if you hit a key on a piano, a string is set in motion and moves back and forth. In both cases, you establish a cycle and, since the cycle is periodically repeated, you get frequencies. The drum has a low frequency (approximately 50 cps); the top note on the piano has a higher frequency (approximately 4100 cps). A complete range of frequencies exists, depending upon the musical instrument and how something in the musical instrument vibrates.

Of course, frequencies also apply to solid materials. If you strike a solid piece of metal with a hammer, you hear something. The something you hear is called sound. And, while you can't get your ear inside a solid piece of metal, you of course realize that sound can travel through a solid material.

Which of the following statements is false?

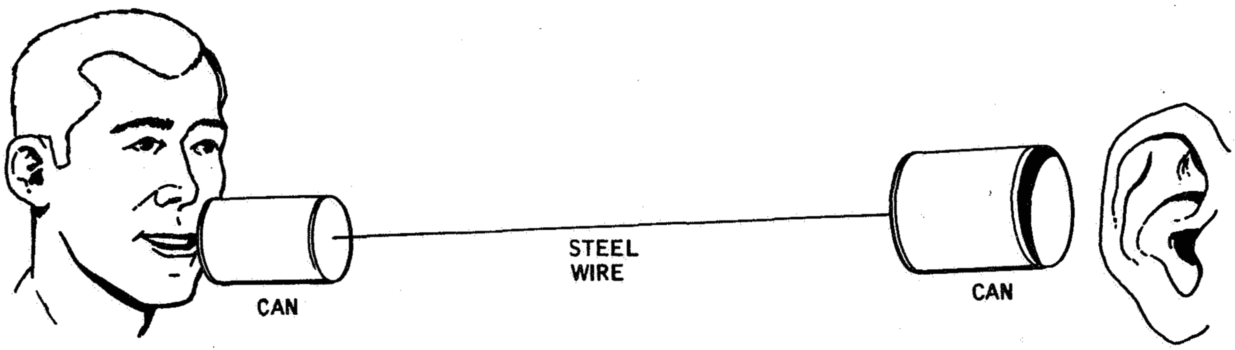
Sound is a vibration and has a range of frequencies . . . . Page 1-22
Sound travels only in air . . . . Page 1-23

You selected the wrong answer. You were asked "Which of the following statements is false?"

Sound is a vibration and has a range of frequencies (your selection)

Sound travels only in air (the correct selection)

We have just learned that sound is a vibration, has a range of frequencies, and travels both in air and in metals. If you don't believe that sound travels in metal, then try the following experiment.

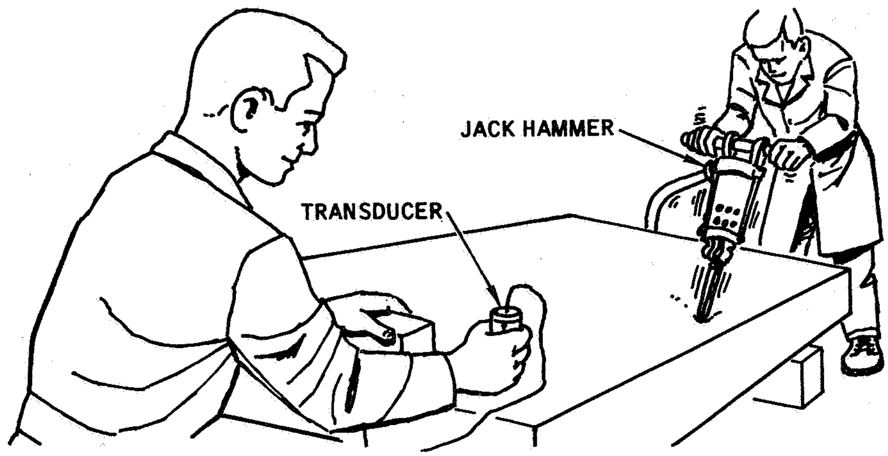


Connect a steel wire between two tin cans, pull the cans apart so that the wire is taut, and talk into one can while someone listens at the other tin can. You will transmit your voice through the wire. Thus, you can prove that sound travels through a metal.

Turn to page 1-23.

From page 1-21

Good! You recognized that sound travels in metal as well as in air, sound is a vibration, and sound has a range of frequencies.



The above illustration shows two men injecting vibrations into a solid. The man with the jack hammer is making lots of noise (sound) and you can hear it. The up and down action of the jack hammer has a definite frequency and is injecting energy (vibrations) into the solid.

The second man is doing the same thing - injecting vibrations (energy) into the solid, but you can't hear anything. Why? Man can only hear vibrations (sound) up to about 20, 000 cps. And the man with the transducer is using a higher frequency (5, 000, 000 cps). Later, we will learn more about the transducer. For the moment, just remember that it does the same job as the jack hammer - or your repeated tapping a piece of metal with a hammer.

Normally, you think of sound as something you hear. Your range of hearing extends to 20, 000 cps. The word "sound" is also used at frequencies above 20, 000 cps. Such sound is called "ultrasonic sound" or, since we are thinking of sound as a vibration, we can call it "ultrasonic vibrations." Both terms (sound and vibrations) are used interchangeably.

Vibrations above the range of human hearing are called...

sound . . . . Page 1-24

ultrasonic vibrations . . . . Page 1-25

From page 1-23

You are not really wrong, but you did not select the best answer. True, vibrations above the range of human hearing are called sound; however, it's better to call them ultrasonic vibrations.

Some people think of sound as only something they hear. Yet, we have seen that the term is applied to sound frequencies above the range of human hearing. The better way to look at it is to think in terms of ultrasonic vibrations. The word "ultra" means beyond the range or limits of something. The word "sonic" means of, or pertaining to, or using sound waves.

Turn to page 1-25.

Good! You selected the better answer. Vibrations above the range of human hearing are called ultrasonic vibrations (your answer). Of course, the alternate answer "sound" was not incorrect, but it is better to think of sound as a vibration.

Ultrasonic sound is defined as...

vibrations above 20,000 cps . . . . Page 1-26

vibrations below 20,000 cps . . . . Page 1-27

Right! Ultrasonic sound is defined as vibrations above 20,000 cps (cycles per second). Note that we are using two terms: sound and vibrations. For our purposes in ultrasonic testing, the two terms mean the same thing.

Which of the following definitions do you feel is the best definition for ultrasonic testing purposes. Sound is defined as...

something you hear . . . . Page 1-28

a vibration that transmits energy by small material displacements . . . . . . Page 1-29

No. You're incorrect when you say that ultrasonic sound is defined as vibrations below 20,000 cps. Recall that ultrasonic sound is defined as sound above the range of human hearing and you can't hear sounds above 20,000 cps.

Turn to page 1-26.

From page 1-26

No, you did not select the best definition when you said that sound is something you hear. The better definition, for ultrasonic purposes, is to say that sound is a vibration that transmits energy by small material displacements.

After all, what you are really interested in is the response or reaction of a specimen to sound. The specimen reacts by affecting the movement of small material displacements. For example, you would expect a crack in the specimen to affect the movement of material displacements - wouldn't you? Certainly.

Turn to page 1-29.

Excellent. You have the concept. The best way to define sound for our purposes is to say that it is <u>a vibration that transmits energy by small material displacements</u>. Later you will see that these displacements are affected by the specimen and provide a method for learning something about the specimen.

The term "ultrasonic sound" is often used in place of the term "ultrasonic vibrations." Both terms are common in the field of ultrasonic testing. Throughout this handbook, we will use both terms. Actually no problem or confusion will exist if you keep in mind the fact that <u>ultrasonic sound means</u>...

small material displacements vibrating at frequencies above 20,000 cps

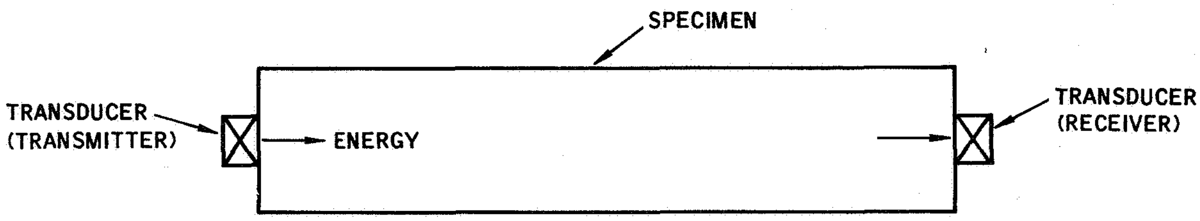
. . . . Page 1-30

small material displacements vibrating at frequencies below 20,000 cps

. . . . Page 1-31

Correct again! Ultrasonic sound (or ultrasonic vibration) is small material displacements vibrating at frequencies above 20,000 cps. And of course, this represents a movement of energy.

Ultrasonic testing is the process of applying ultrasonic sound to a specimen and learning something about the specimen. Since ultrasonic sound is energy moving by small material displacements through the specimen you would expect the specimen to affect the movement. For example, the specimen may absorb the energy or reflect the energy. In either case, the specimen's reaction or response provides a means of learning something about the specimen.



Shown above is the injection of energy into a specimen. The energy is originating in something called a "transducer" which causes material displacements within the specimen. These displacements move through the specimen and are sensed by another transducer positioned at the opposite end of the specimen. Would you say that the receiving transducer will pick up the specimen's reaction to the ultrasonic vibrations?

No . . . . Page 1-32

Yes . . . . Page 1-33

From page 1-29

Stop! You have missed, or forgotten, a point. You said that ultrasonic sound is small material displacements vibrating at frequencies below 20,000 cps. You should have said above 20,000 cps. Remember, ultrasonic means above the range of human hearing and you can't hear above 20,000 cps.

Turn to page 1-30.

You selected the wrong answer ("no") so apparently you don't think the receiving transducer will pick up the specimen's response or reaction to the ultrasonic vibrations.

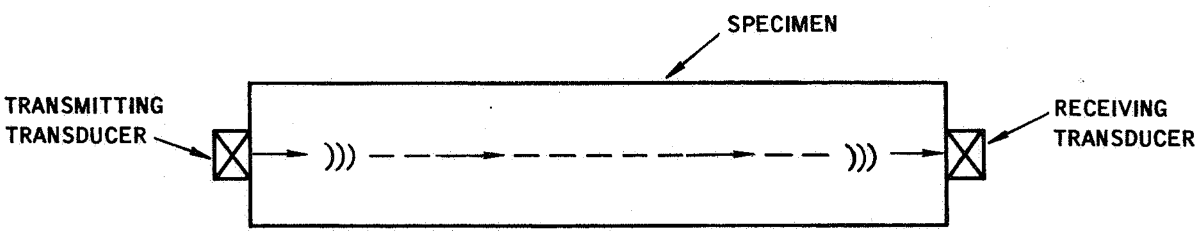
We have defined ultrasonic testing as the process of applying small material displacements to a specimen and learning something about the specimen as the specimen reacts to the movement of the displacements through the specimen. The transmitting transducer injects energy in the form of small material displacements into the specimen and the receiving transducer senses this energy at the opposite end of the specimen. What the specimen does to this energy between the two transducers provides the basis for ultrasonic testing. The receiving transducer <u>will</u> pick up the specimen's response or reaction to the ultrasonic vibrations.

Turn to page 1-33.

Right. You selected the correct answer. The receiving transducer <u>will</u> pick up the specimen's reaction to ultrasonic vibrations.

We also find that the energy transmitted by a transducer can be either <u>pulsed</u> or <u>continuous</u>. Sometimes a transducer injects energy into a specimen for a very short period of time (in the order of microseconds), then pauses for a short period of time before transmitting again. This is called "pulsed sound" and is defined as a short group of vibrations before or after which no vibrations occur. At other times a transmitting transducer applies vibrations to a specimen continuously. This is called "continuous sound". Both pulsed and continuous sound are used in ultrasonic testing, depending on the method of testing.

The transmitting transducer below is shown injecting a group of vibrations))) into a specimen.



This group of vibrations moves through the specimen and is sensed by the receiving transducer. After a short period of time, a second group of vibrations are injected into the specimen. Again, this is sensed by the receiving transducer. We call this type of transmission...

pulsed sound . . . . Page 1-34
continuous sound . . . . Page 1-35

You're right. The transmitted sound was pulsed sound, not continuous sound. The difference between pulsed sound and continuous sound is really a matter of time.

If the transmitting transducer vibrates only once, a single material displacement is injected into the specimen, flows through the specimen, and is sensed by the receiving transducer. This is pulsed sound.

On the other hand, if the transducer rapidly and repeatedly vibrates back and forth, a series of displacements move into and through the specimen. This, we call continuous sound.

There are times when we need a series of pulses (material displacements) with sufficient time between pulses to permit us to view a response indication. Our equipment even includes controls to adjust the time between pulses.

Later we will learn that sound is used in different ways. The important fact to keep in mind at this time is that sound can be...

only continuous . . . . Page 1-36

either pulsed or continuous . . . . Page 1-37

Incorrect. The sound was pulsed sound, not continuous sound as you selected.

The difference between pulsed sound and continuous sound is one of time. If we tap a specimen once with a hammer, we have injected a pulse of sound into the specimen. On the other hand, if we repeatedly tap the specimen rapidly (e.g., 10 times a second or 10 cps) we are injecting continuous sound into the specimen. What if we tap the specimen twice every 10 seconds? We say it is a pulsed sound. Later you will see that both types of sound are used in ultrasonic testing. For the moment, just realize that sound is not always continuous.

Turn to page 1-34.

From page 1-34

Wrong. Sound can be either pulsed or continuous. You said it could only be continuous. This is not so. We just saw that you could apply a single pulse to the specimen.

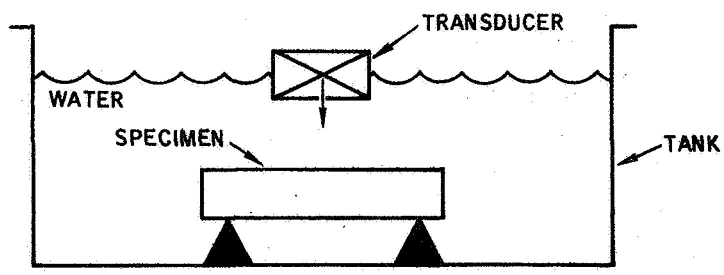
For example, if we tap the specimen once with a hammer, we put a single material displacement into the specimen. This is a pulse of sound. On the other hand, if we rapidly and repeatedly strike the specimen we are applying continuous sound to the specimen.

Turn to page 1-37.

Fine! You realize that sound can be either pulsed or continuous. It's a question of time, isn't it ?

So far we have been talking in terms of small material displacements moving through a solid material. We have found that these displacements have a frequency above 20,000 cps. And we call these displacements vibrations or sound.

Sound is not limited to solid materials. Other mediums such as air, water, oil, grease, etc., will also transmit ultrasonic sound. Of course, you suspected that this is true since the sound you hear travels in air and in water. Later we will learn that sound travels at different speeds in different media and will change speed...let's call it velocity...as the sound moves from one medium to another.

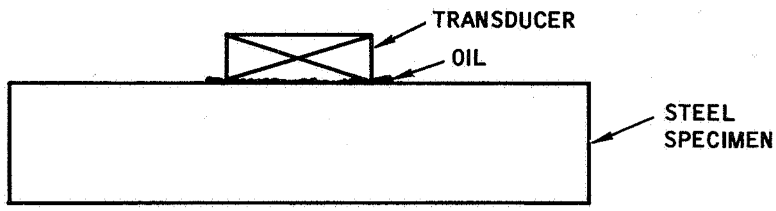


The above illustration shows a transducer positioned in water above a specimen. The transducer is generating vibrations (sound). The sound will...

move through the water and enter the specimen . . . . Page 1-38

not move through the water to the specimen and enter the specimen . . . Page 1-39

Yes, you are right. The sound will move through the water to the specimen and will enter the specimen. In fact, the sound in the specimen will also move from the specimen, through the water, back to the transducer. Water is a medium that conducts sound.



The above illustration shows the use of oil between a transducer and a steel specimen. The sound developed by the transducer will...

pass through the oil to the steel specimen . . . . Page 1-40

be blocked by the oil and not pass through to the steel specimen . . . . Page 1-41

No, you are not right. You said that the sound will not move through the water and enter the specimen. Actually, it will.

The transducer is positioned in the water above the specimen which is a solid (e.g., steel). As the transducer generates sound, this sound will enter the water, pass through the water, and strike the steel specimen. Since the specimen transmits sound, the sound will enter the specimen. Of course, some of the sound will be reflected. Note that this is the basis for underwater SONAR used by submarines to detect objects under the water.

Turn to page 1-38.

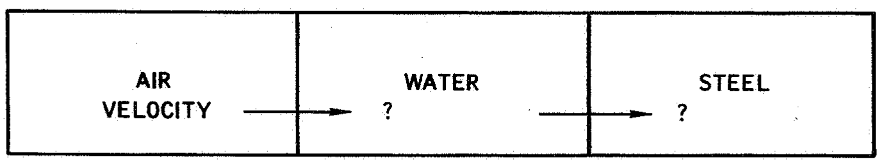
[redacted]

That's right. Oil transmits sound and the vibrations generated by the transducer will pass through the oil to the steel specimen.

So far, we have seen that water and oil will transmit sound (ultrasonic vibrations). The same is true for grease. Air, however, presents a problem.

Of course, you know that sound travels through air. Unfortunately, air doesn't do a very good job of transmitting sound. In fact, that's why we put oil or grease between the transducer and the steel specimen. Our purpose is to get rid of the air. Air gets in our way, slows down the speed (velocity) of sound, and prevents sound from entering the specimen.

We also find that the movement of ultrasonic vibrations is not the same for all media. This movement...let's call it velocity...is constant for a given medium but varies from one medium to another. For example, the sound velocity in steel is approximately four times greater than that in water.



Visualize a condition in which sound is moving through air, enters water and then passes into a steel specimen. Will the velocity of sound change as it moves into the water and into the steel specimen?

Yes . . . . Page 1-42

No . . . . Page 1-43

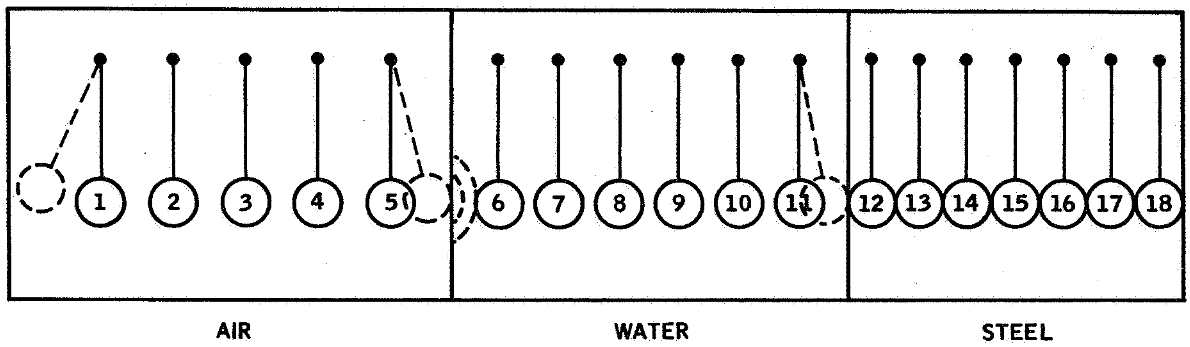
No, you are not correct when you say that the sound developed by the transducer will be blocked by the oil and will not pass through to the steel specimen.

Recall that sound will pass through air, water, oil, grease, and solid materials such as steel. Later we will see that oil or grease is intentionally placed between the transducer and the specimen to make it easier for the sound to move from the transducer to the specimen.

Turn to page 1-40.

From page 1-40

Good. You have the concept. The velocity of sound will change as it moves from air into water and then into the steel specimen.



Visualize that the balls shown above represent the internal structure of air, water, and steel. If we displace ball 1 and release it, we start a sequence which ends with an effect on ball 18. Note that it takes time for the ball to swing through the distances between the balls. The effect of the ball moving through the row of balls can be called a <u>pulse</u> of sound. And if the balls were continuously swinging, we could say the sound is <u>continuous</u>. In either case, the sound has a velocity and this velocity will change as the sound moves from one medium to another medium.

The above illustration also shows that particle density varies from one medium to another. It is this variation plus the particle elastic properties that determines the velocity of sound in a given medium.

Select the best completion for the following statement.

Sound velocity within a given medium is dependent upon the medium's...

particle density alone . . . . Page 1-44

particle density and elasticity. Page 1-45

You are wrong when you say "No". Recall that the velocity of sound is constant for a given medium but changes from one medium to another. For example the velocity in steel is approximately four times the velocity in water and 19 times the velocity in air. This means the velocity in steel is greater than water or air. And the velocity in water is greater than in air. That's why the correct answer to the question is "Yes". The velocity changes as it moves into the water and then into the steel specimen.

Turn to page 1-42.

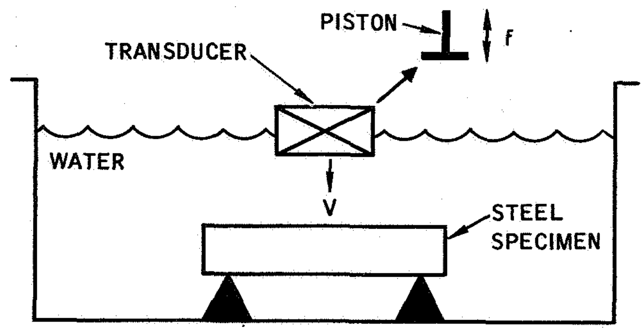
You missed the point. You said that sound velocity depends upon the medium's particle density alone. This is not quite true.

Density does affect sound velocity but so does the medium's elastic properties. Recall that the transmission of ultrasonic vibrations through a medium is related to the elastic property of the medium. Some media have more elasticity than others and it is this elasticity that transmits the energy from particle to particle. Therefore, we can see that the velocity with which sound travels through a medium depends upon not only the density but also the elastic constants of the medium.

Turn to page 1-45.

Right. A sound's velocity depends on the particle density of the medium as well as the medium's elasticity.

Shown below is a transducer placed in water above a steel specimen.



Visualize that the transducer acts like a piston that moves back and forth at a specific frequency (f).

As the transducer vibrates, energy is injected into the water and this energy moves through the water as ultrasonic vibrations. The velocity (v) of the vibrations is determined by the water. Recall that the velocity is constant for a given medium.

When the ultrasonic sound strikes the steel specimen, the sound enters the specimen. And within the specimen, the velocity is a constant. Will the velocity in the steel specimen be the same as the velocity in the water?

Yes . . . . Page 1-46

No . . . . Page 1-47

You said "Yes." The correct answer is "No." The question was "Will the velocity in the steel specimen be the same as the velocity in the water?"

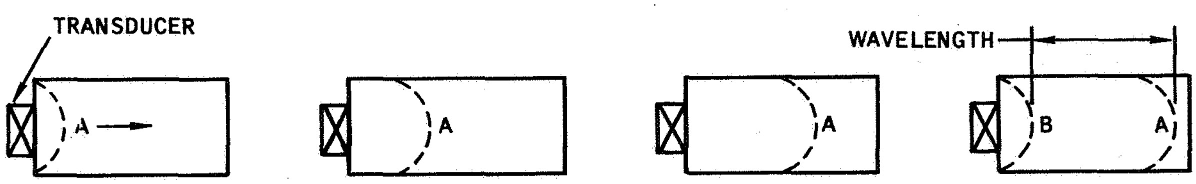
We just learned that each medium (air, water, oil, grease, and steel) has a unique response to sound. The velocity of sound will be the same in the specific medium, but the velocity will vary from one medium to another medium. For example, the velocity of sound in steel is approximately four times the velocity of sound in water. This means that sound moving through water will increase its velocity as it moves into steel. It is also true that the velocity of sound leaving the steel will slow down as it moves into the water.

Turn to page 1-47.

[redacted]

Fine. You're with the concept. The velocity in the steel specimen will not be the same as the velocity in the water.

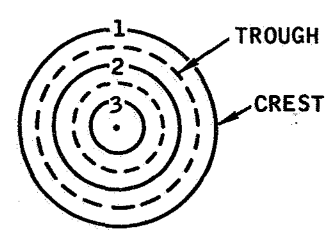
Now that you have the idea of velocity, let's consider the term "wavelength". Shown below is a transducer exerting a momentary pressure (small material displacement) on a specimen.



This displacement will be successively transmitted through the specimen as a series of small material displacements. Realize that the transducer returns to its center or rest position after injecting the small displacement into the specimen.

At a certain point in time, the transducer will repeat the cycle with a second displacement (B). If this occurs while the initial displacement is still moving through the specimen, the result will be two displacements within the specimen. The distance between these two displacements is called the wavelength. Note that the wavelength represents the distance the displacement moves before the next displacement in the same direction arrives at the same point as that occupied by the first displacement.

When something is dropped on a water surface as shown at the right, a series of waves are formed. Wave 1 was the first wave generated from the center. The distance between wave 1 and wave 2 is...



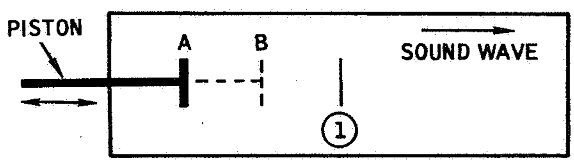
a wavelength . . . . Page 1-48

not a wavelength . . . . Page 1-49

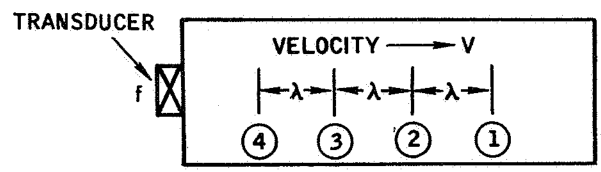
From page 1-47

Correct! The preceding example shows the concept of wavelength. The distance between wave 1 and wave 2 is a wavelength. Wavelength can also be stated as the distance a wave advances while a particle makes one complete vibration or orbit.

Now let's visualize that a transducer acts like a small piston near the surface of the specimen as shown in view A, below. As this piston moves back and forth at a fixed frequency, small areas within the specimen are periodically displaced. The vertical line 1 in view A, denotes an area of maximum displacement which is caused by the piston moving from A to B.



VIEW A



VIEW B

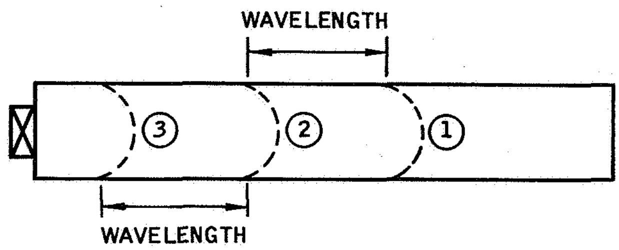
View B illustrates a distribution of maximum displacements caused by the piston (transducer). Note that the first maximum displacement has moved forward and is followed by additional maximum displacements. The distance between two adjacent displacements is a wavelength (note the symbol that is used; it's called LAMBDA).

At this point, the important fact to remember is that each vertical line in view B represents a wave. Actually it represents a point on a wave; however, for our purposes let's simply call it a wave.

Turn to page 1-50.

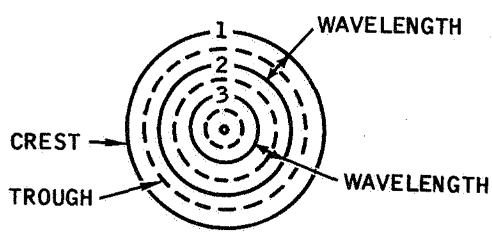
Incorrect. You missed the concept when you said that the distance between wave 1 and wave 2 is not a wavelength.

A wavelength is the distance between two points. View A, below, illustrates three identical displacements in a solid material. The distance between two adjacent displacements is a wavelength.



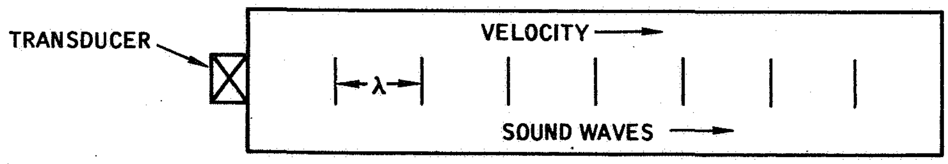
VIEW A

View B illustrates the same thing happening in water. Again, the distance between two adjacent points is a wavelength.



VIEW B

Turn to page 1-48.



$\lambda = \frac{V}{f}$ OR WAVELENGTH = $\frac{\text{VELOCITY}}{\text{FREQUENCY}}$

f REPRESENTS FREQUENCY

λ IS CALLED LAMBDA

The above illustration shows a transducer vibrating at a fixed frequency (f) and injecting sound waves into a specimen. These sound waves move at a fixed velocity (v) through the specimen. The distance between two adjacent waves is defined as the wavelength (λ). Again, we call this symbol LAMBDA.

A definite relationship exists between the wavelength and the ratio of the velocity to the frequency as shown in the formula above. For a given specimen and fixed frequency, a definite wavelength exists.

Note that the wavelength can be changed if the frequency of the transducer vibration changes. ($\lambda = \frac{v}{f}$). For example, if the frequency is increased the ratio v/f becomes smaller. This means the wavelength becomes smaller. Another way of saying this is to make the statement that you can shorten the wavelength by increasing the frequency. Later on you will find that to detect small discontinuities in the specimen you will need high frequencies. So remember, if you change the frequency, you change the wavelength. The higher the frequency, the shorter the wavelength.

Sometimes you want long wavelengths. To get these you would...

raise the frequency . . . . Page 1-51

lower the frequency . . . . Page 1-52

From page 1-50

No, you are not correct when you say that we must raise the frequency if we want long wavelengths. Look at the formula again.

$$\text{WAVELENGTH} = \frac{\text{VELOCITY}}{\text{FREQUENCY}} \qquad \text{or} \qquad \lambda = \frac{v}{f}$$

Recall that velocity is a fixed value for a given specimen; therefore, the wavelength varies as the frequency varies. Note that if the frequency is lowered, the wavelength increases (gets longer).

examples:

$$\frac{10\ (\text{VELOCITY})}{10\ (\text{FREQUENCY})} = 1\ (\text{WAVELENGTH})$$

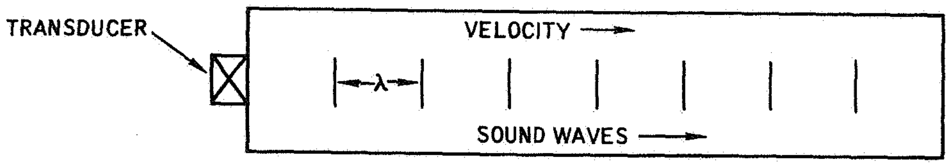
$$\frac{10\ (\text{VELOCITY})}{5\ (\text{FREQUENCY})} = 2\ (\text{WAVELENGTH})$$

$$\frac{10\ (\text{VELOCITY})}{1\ (\text{FREQUENCY})} = 10\ (\text{WAVELENGTH})$$

Turn to page 1-52

From page 1-50

Right! If the frequency is lowered, the wavelength will increase.



We have seen that a relationship exists between the frequency (f) of the transducer and the wavelength (λ). Since the velocity (v) is constant for a given specimen, the wavelength depends upon the frequency of the transducer.

Select the formula that relates the three factors.

$\lambda = \frac{f}{v}$ . . . . Page 1-53

$\lambda = \frac{v}{f}$ . . . . Page 1-54

From page 1-52

You selected $\lambda = \frac{f}{v}$. The correct answer is $\lambda = \frac{v}{f}$.

Think of it this way. The wavelength (λ) is a ratio. The top number of the ratio is a fixed value. This is the velocity (v) which is constant for a given specimen.

The bottom part of the ratio is a variable. This is the test frequency (f). For a given test system, the test frequency can be varied. We can use a low frequency or a high frequency. As we change the frequency we change the wavelength. Look at the formula again.

$$\text{WAVELENGTH} = \frac{\text{VELOCITY}}{\text{FREQUENCY}} \quad \text{or} \quad \lambda = \frac{v}{f}$$

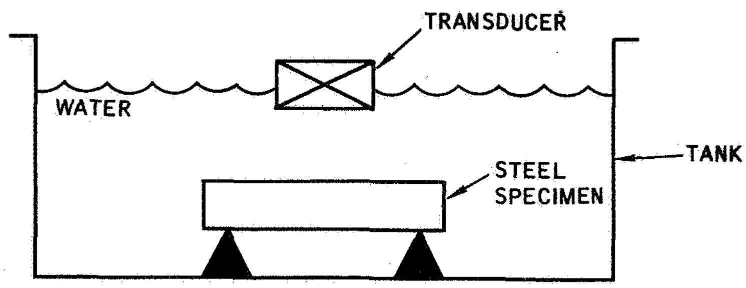
λ is called LAMBDA.

Turn to page 1-54.

From page 1-52

Correct again! $$\text{WAVELENGTH} = \frac{\text{VELOCITY}}{\text{FREQUENCY}} \quad \text{or} \quad \lambda = \frac{v}{f}$$

Note that wavelength is a ratio of a fixed value (velocity) divided by a variable (frequency).



The transducer shown above is vibrating at a fixed frequency (f) and injecting ultrasonic sound through water to a steel specimen. You have just learned that the wavelength is a ratio (v/f). Earlier you learned that the velocity of sound is constant for a specific medium (e.g. water or steel) but varies from one medium to another. Based on these facts, we can say...

the wavelength is the same in both the water and
in the steel specimen . . . . Page 1-55

the wavelength is not the same in both the water and
in the steel specimen . . . . Page 1-56

No, you're wrong when you say that the wavelength is the same in both the water and in the steel specimen.

Recall that $\lambda = \frac{v}{f}$ or $\text{WAVELENGTH} = \frac{\text{VELOCITY}}{\text{FREQUENCY}}$

Now realize that we have two velocities. One velocity is the velocity of sound in water; the other is the velocity of sound in the steel specimen. Since the test frequency (f) remains unchanged, this means that the wavelength (λ) must change.

It is interesting to note that the velocity in steel is approximately four times the velocity in water. Using the formula ($\lambda = v/f$), this means that the wavelength is longer in steel than in water.

For the moment, just keep in mind that the wavelength varies as sound moves from one medium to another.

Turn to page 1-56.

Fine! You realized that the wavelength varies from one medium to another medium and this is caused by the fact that the velocity of sound varies with the medium.

Turn to page 1-57.

From page 1-56

1. The next few pages are different from the ones which you have been reading. There are ____________ arrows on this entire page. (Write in the correct number of arrows.) Do not read the frames below. FOLLOW THE ARROW and turn to the TOP of the next page. There you will find the correct word for the blank line above.

5. energy

6. If a surface is depressed and held, the distance the surface moved is called a d________________t.

10. period

11. A vibration is a back and forth movement of energy passing through a specimen as a series of small material displacements. The frequency of vibration used in ultrasonic testing is normally above the range of human hearing. When the frequency is within the range of human hearing, the vibration is called ______________.

15. velocity

16. The velocity of sound is dependent on the density and elastic properties of the medium. And velocity varies from one medium (e.g. water) to another (e.g. steel) but is c____________ within a given medium.

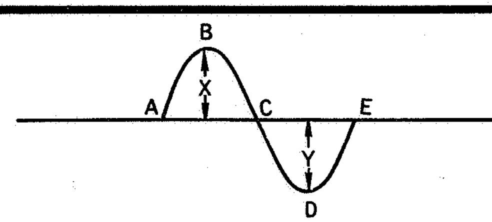
This is the answer to the blank in Frame number 1.

1. four Frame 2 is next

2. These sections will provide a review of the material you have covered to this point. There will be one or more blanks in each f__________.

Turn to the next page.
Follow the arrow.

6. displacement

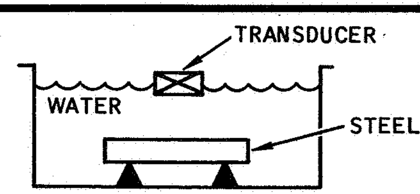


7. A vibration is something that moves back and forth as shown above. The distance X is a displacement in one direction; the distance Y is a displacement in the opposite direction. One complete movement, first in one direction and then in the opposite direction, is called a c__________.

11. sound

12. Vibrations above 20,000 cps are called ____________ vibrations.

16. constant



17. This view illustrates a transducer injecting sound through water into a piece of steel. The velocity of sound in water is a fixed value; the velocity of sound in steel is also a fixed value. As the sound moves from the water to the steel, the velocity of the sound will c________e.

2. frame

3. By following the arrows <u>or instructions</u> you will be directed to the section which follows in sequence. Each section presents information and requires the filling in of ____________________.

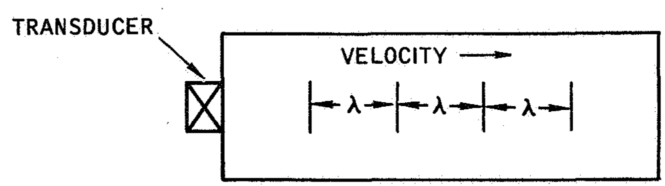
7. cycle

8. Time is required for a vibration to move through one complete cycle. Of course, most vibrations pass through several cycles. The number of cycles in one second is called the f_________________.

12. ultrasonic

13. In ultrasonic testing, the term "vibration" is used interchangeably with the term "______________".

17. change



18. This view shows a transducer injecting sound into a specimen. Each vertical line represents a sound wave (or a point on a sound wave). The distance between two sound waves is called a w____________________.

3. blanks (or spaces or words)

4. Ultrasonic testing is concerned with the back and forth movement of small areas of material within a test specimen. This back and forth movement is called a v____________.

8. frequency

9. Frequency is often abbreviated as cps. This means c__________ p__________ s__________.

13. sound

14. In ultrasonic testing, the sound injected into the specimen can be pulsed or continuous. The device used to inject the sound (a vibration) into the specimen is called a t__________.

18. wavelength

19. The symbol for a wavelength is λ (called LAMBDA). A definite relationship exists between the wavelength and the ratio of the velocity to the frequency ($\lambda = v/f$). Since the velocity is constant for a given medium, the wavelength will decrease (become shorter) if the frequency is __________d.

4. vibration

5. Since a vibration is doing work by moving material within a test specimen, a vibration is really a back and forth movement of e____________.

Return to page 1-57, frame 6.

9. cycles per second

10. A relation exists between the frequency and the time required to complete one cycle. If the frequency is known, we can divide the frequency into one (1/f) and get the time required for one complete cycle. The time required for one complete cycle is called the p____________.

Return to page 1-57, frame 11.

14. transducer

15. Ultrasonic sound moves as a series of small material displacements and is energy in motion. The speed of movement through the material is called the v____________.

Return to page 1-57, frame 16.

19. increased

20. This completes the review of Chapter 1. Turn to page 2-1.

You should not have turned to this page. The instructions were to return to page 1-57, frame 6, and continue with the review.

You should not have turned to this page. The instructions were to return to page 1-57, frame 11, and continue with the review.

You should not have turned to this page. The instructions were to return to page 1-57, frame 16, and continue with the review.

Disregard this page. The instructions were to turn to page 2-1.

In Chapter 1 you learned that ultrasonic sound is a vibration which moves through a specimen as a series of small material displacements. You also learned that something called a "transducer" can be used to inject sound into a specimen. Now let's define a transducer.

A transducer is a device that converts energy from one system to another. For example: electrical energy to mechanical energy; or mechanical energy to electrical energy.

The speaker in a radio is one example of a transducer. In this case, electrical energy is applied to a coil surrounding a portion of the speaker and this causes the speaker to move back and forth (mechanical movement). The pickup on your record player is another example. In this instance, the record causes mechanical movement of a needle which exerts a pressure on a crystal (a part of the pickup). Since the crystal has the property of developing an electrical output (energy) when the pressure on the crystal is varied, the transducer is converting mechanical energy to electrical energy.

Visualize that we have a crystal one inch square and that we are alternately applying and removing electrical energy through two wires connected to the crystal. As we do so, we notice that the crystal vibrates. Under these conditions, would you call the crystal a transducer?

No . . . . Page 2-2

Yes . . . . Page 2-3

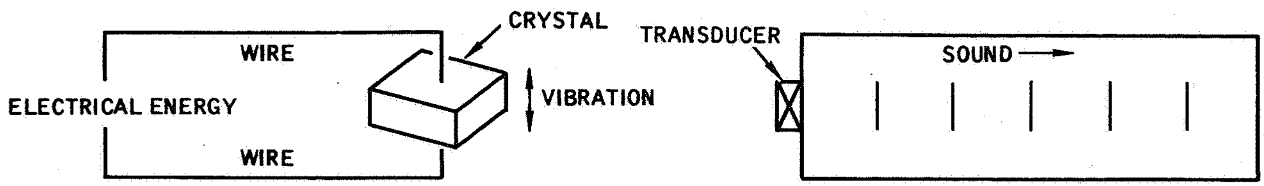
Your answer "no" is not correct. What we did was to apply electrical energy to a crystal. What we got was a mechanical vibration. Thus we went from electrical energy to mechanical energy.

Recall that a transducer is a device that converts energy from one system to another system. Since we converted electrical energy to mechanical energy (a vibration), we used a transducer. In ultrasonic testing the term "crystal" is often used interchangeably with the term "transducer".

Turn to page 2-3.

From page 2-1

You're right, of course. The crystal can be called a transducer. In fact, the two terms "crystal" and "transducer" are used interchangeably in ultrasonic testing.



VIEW A

VIEW B

View A, above, illustrates electrical energy being applied through two wires connected to a crystal. The ability of this crystal to convert electrical energy to mechanical energy is known as the "piezoelectric effect". Electrical energy causes a piezoelectric crystal to expand and contract, forming mechanical vibrations.

View B, above, illustrates a piezoelectric crystal ... let's call it a transducer ... positioned against a specimen. From this illustration, we can see that a transducer is a sound generator (or ultrasonic generator) which generates vibrations. Note that sound is shown moving through the specimen. Recall that a vibration is energy in motion and sound moves through a specimen by a series of small material displacements.

A moment ago, we mentioned that a record player pickup is a crystal which is vibrated by a record needle. As the needle moves, pressure changes are made on the crystal and the crystal generates an electrical charge. This is known as the "reverse piezoelectric effect". Mechanical energy is converted to electrical energy.

Which of the following statements is true?

A peizoelectric transducer converts electrical energy to mechanical energy but does not convert mechanical energy to electrical energy . . . . Page 2-4

A piezoelectric transducer converts electrical energy to mechanical energy and converts mechanical energy to electrical energy . . . . Page 2-5

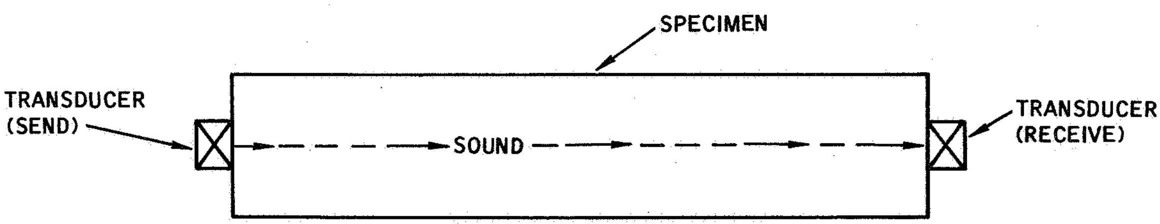
From page 2-3

You're wrong when you say that the statement "A piezoelectric transducer converts electrical energy to mechanical energy but does not convert mechanical energy to electrical energy". The statement is false because the transducer will also convert mechanical energy to electrical energy. Recall that the crystal in the record player made this conversion.

Turn to page 2-5.

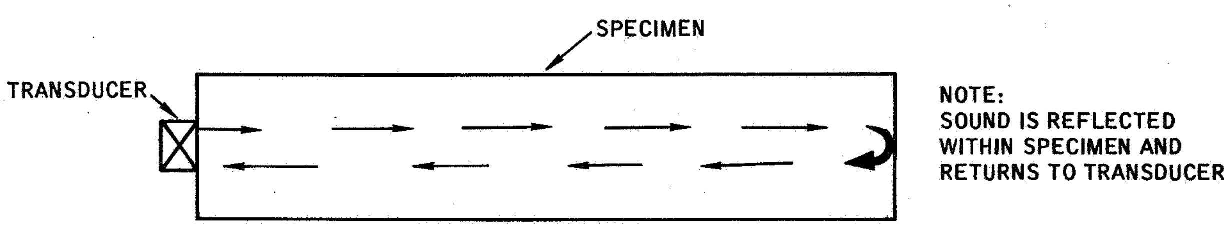
Good! You selected the statement that is true. A piezoelectric transducer converts electrical energy to mechanical energy (a vibration) and also converts mechanical energy to electrical energy.

Of course, this means that a transducer can both send and receive energy. For example, if we locate transducers at opposite ends of a specimen as shown in view A below, we can use one transducer to send energy (sound) into the specimen and then use the other transducer to receive the sound.



VIEW A

View B illustrates the use of only one transducer on a test specimen.



VIEW B

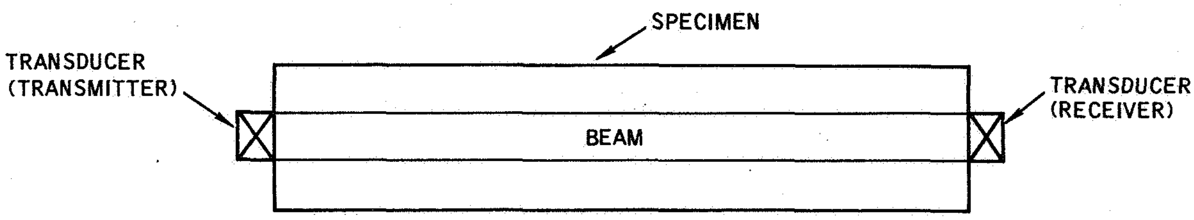
With one transducer, visualize that the transducer is momentarily energized by an electrical source. Under this condition, the transducer momentarily vibrates and sends a pulse of sound into the specimen. The transducer then stops vibrating. If the sound within the specimen is reflected and returned to the transducer, will the transducer receive the sound and vibrate again?

Yes . . . . Page 2-6

No . . . . Page 2-7

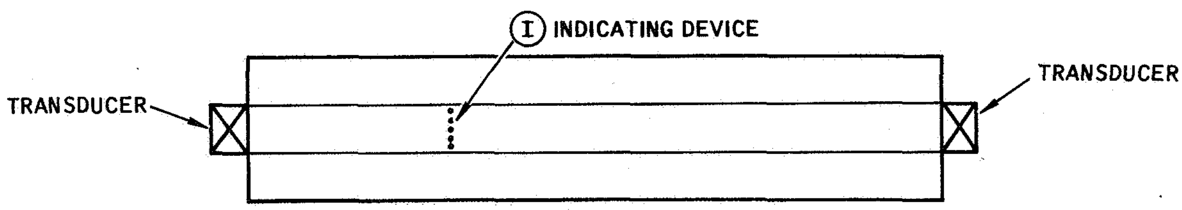
Fine. You're right when you say that the transducer will receive the sound and vibrate again. In ultrasonic testing, it is a common practice to use the same transducer to send and receive sound.

Ultrasonic testing is based upon the fact that a transducer will inject a beam of energy into a specimen and the specimen will react or respond to this beam.



VIEW A

View A shows a transducer injecting a beam of energy into a specimen. Note that this beam passes through the specimen and is sensed by another transducer. Also note that there are areas within the specimen that are not directly in the path of the beam of energy.



VIEW B

Imagine that we have a device that can be inserted into the specimen as shown in view B, and used to measure the amount of energy at various points across the beam. As we move the device across the beam, we will find that all points will be of the same intensity. And "intensity" is defined as the relative strength of a sound beam within a given area.

From this we can say...

the intensity across the beam of energy is not constant . . . . Page 2-8

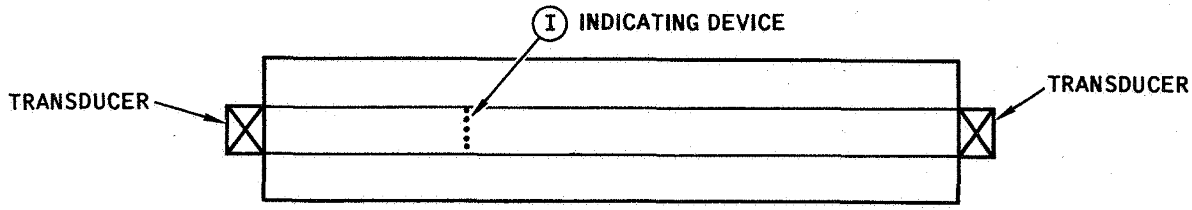
the intensity across the beam of energy is constant . . . . Page 2-9

You are not correct when you say that the transducer will not receive the sound and vibrate again.

A piezoelectric transducer will work both ways. The same transducer can be used to send and receive sound. First we can generate a sound by momentarily applying electrical energy to the transducer. When the electrical energy is removed, the transducer stops vibrating. Sound returning to the transducer through the specimen will exert a pressure on the transducer and will cause the transducer to generate electrical energy. Thus the same transducer can be used to send and receive sound.

Turn to page 2-6.

You're wrong when you say that the intensity across the beam of energy is not constant. The intensity across the beam of energy is constant.



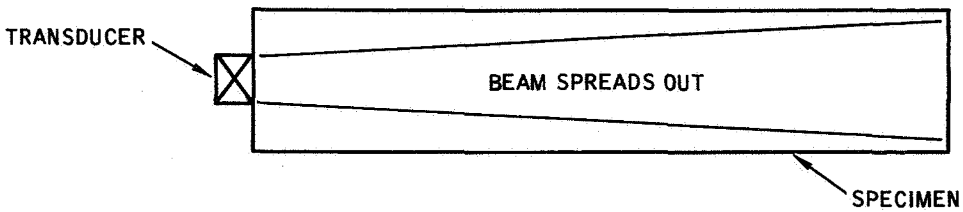
Recall that we used an indicating device to measure the intensity at different points across the beam and that you learned that all points have the same intensity.

Turn to page 2-9.

From page 2-6

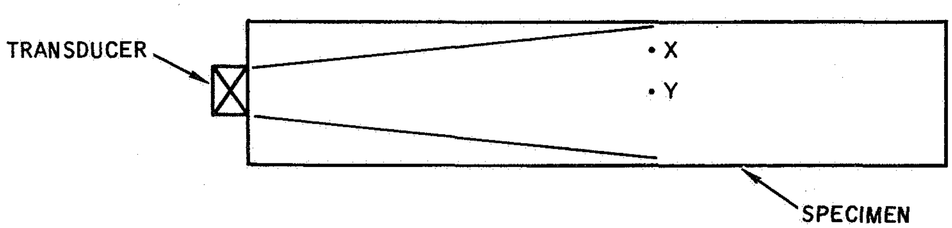
For the moment, you're right. The intensity across the beam of energy is constant.

So far, we have assumed that the beam does not spread out. In actual practice, it does to some extent. In fact, this is common to most beams. For example, a flashlight provides a beam of light which spreads out as it moves away from the front of the flashlight. The same condition exists in a test specimen. A transducer injects a beam of energy into the specimen and this beam will spread out (diverge) as it moves through the specimen.



Now consider what this means in terms of energy (intensity) across the beam. The greatest concentration of energy is in the center of the beam; however, this concentration decreases as you move away from the center. Or another way of saying it is to state that the beam intensity decreases as the distance from the center of the beam increases.

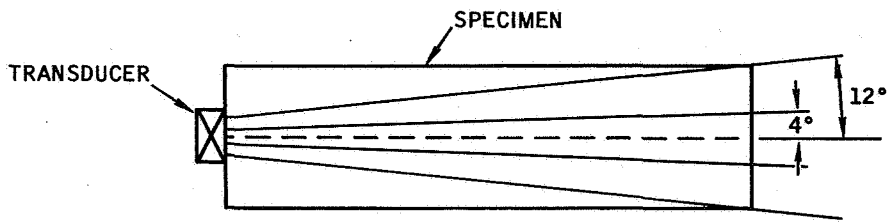
The illustration below shows two points in a beam. Both points are the same distance from the transducer. The intensity at point X will be...



less than at point Y . . . . Page 2-10

the same as point Y . . . . Page 2-11

Right! The intensity at point X will be less than the intensity at point Y. We can say that the intensity (energy) becomes less as we move away from the center of the beam.



Shown above are two different beams within a specimen. Note that one beam spreads only 4 degrees from the center of the beam. The other beam spreads 12 degrees in the same distance. The size of the transducer and the frequency used to excite the transducer causes the difference between the two beams. That is, for a given size transducer, high frequency transducers have narrow sound beams. Low frequency transducers have spreading or diverging sound beams.

By using the proper size transducer and frequency, beam spread can be reduced to where the beam can be considered a straight beam. The intensity across the beam can be considered almost constant.

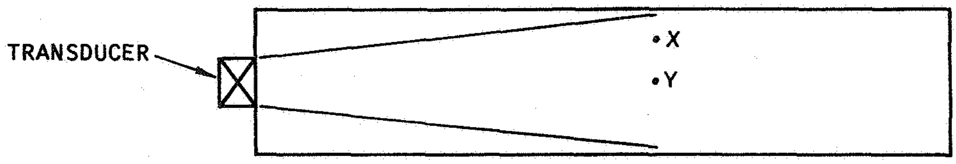
If the proper size transducer is used and the proper frequency is selected so that the beam spread is small, we could say...

ultrasonic sound travels through a specimen as a narrow straight beam of energy . . . . Page 2-12

ultrasonic sound travels through a specimen as a wide, expanding beam of energy . . . . Page 2-13

From page 2-9

You said the intensity at point X will be the same as at point Y. You're wrong.



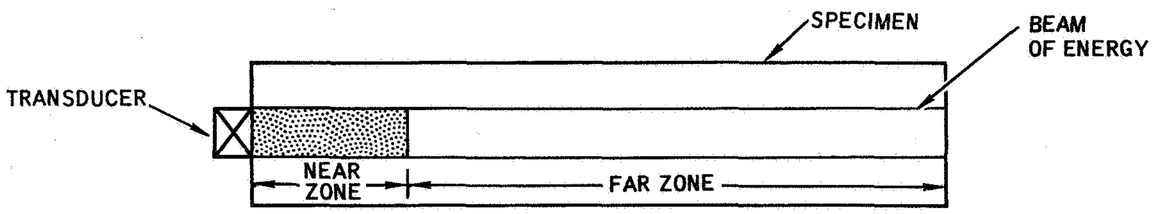
Recall that the intensity (energy) decreases as the distance from the center of the beam increases. This means that the intensity at point X is less than that at point Y.

Turn to page 2-10.

From page 2-10

Correct. Ultrasonic sound can be viewed as a narrow straight beam of energy.

As shown below, the transducer injects a beam of energy into the specimen. This beam is divided into two zones: the "near zone" and the "far zone".



If we had a means of measuring the intensity of the beam at various distances from the transducer like we did at various distances from the center of the beam, we would learn two facts. In the far zone, the intensity (energy) would steadily decrease as the distance from the transducer increases. This is caused by the fact that the specimen is absorbing energy.

In the near zone, a different condition exists. Here we find that the intensity varies irregularly. Localized areas of high and low intensity exist within this area. Later we will learn that this near zone prevents the detection of discontinuities close to the surface of the specimen.

If you place a transducer against a specimen and excite the transducer, a beam of energy enters the specimen. This beam is divided into two zones. The zone containing irregular intensities is called...

the far zone . . . . Page 2-14

the near zone . . . . Page 2-15

You are not correct when you say that the ultrasonic sound would travel through the specimen as a wide, expanding beam of energy. In fact, just the opposite is true.

Of course, some beam spreading occurs; however, by using the proper size transducer and the proper frequency this beam spreading can be minimized. This means we can think of the beam as a narrow straight beam.

Turn to page 2-12.

From page 2-12

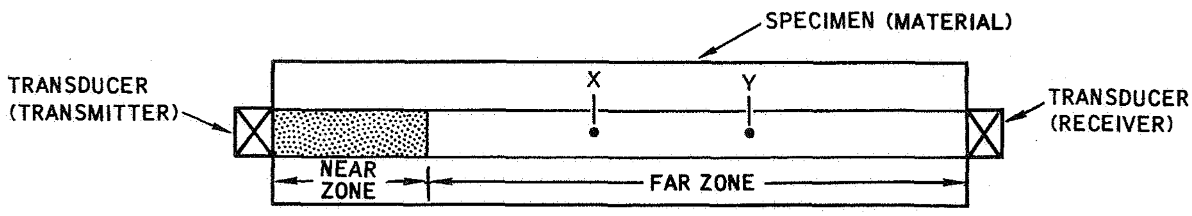
No, you have the zones reversed. You said that the zone containing irregular intensities is called the far zone. You should have said the near zone.

Recall that the far zone is the portion of the beam of energy where the intensity is constant across the beam and where the intensity decreases as the distance from the transducer is increased. This decrease in intensity is caused by the absorption of energy by the specimen.

Turn to page 2-15.

Yes, you're right. The zone containing irregular intensities is called the near zone. And for our purposes, it is not important to know what causes this condition. All we need to remember is that it does exist.

Shown below is a transducer (transmitter) injecting ultrasonic sound into a specimen (material). This sound is being sensed by a second transducer (receiver).



A moment ago, you learned that the intensity of the beam of energy decreases as the distance from the sending transducer increases. Again, intensity refers to the relative strength of a sound beam at a certain point. This means that the intensity at point Y, above, is less than at point X. It also means that the amount of energy delivered to the receiver transducer will be less than the amount injected into the material. The difference in energy represents an energy loss.

The term "attenuation" is used to describe this condition of energy loss. Attenuation means the process of lessening the amount. And this is exactly what happens to ultrasonic sound as it moves through a material. The properties of the specimen or medium cause the attenuation.

Attenuation does...

not exist in the far zone . . . . Page 2-16

exist in the far zone . . . . Page 2-17

From page 2-15

You said that attenuation does not exist in the far zone. This is not correct. Attenuation does exist in the far zone.

Attenuation means a loss of energy as applied to ultrasonic testing. Such a loss of energy occurs in the far zone; thus, attenuation does exist in the far zone.

Turn to page 2-17.

Correct! Attenuation exists in the far zone.

Okay now let's take up the material characteristic used to relate one material to another. It is known as "acoustical impedance" and as the term implies, acoustical impedance (Z) is the sound resistance of a material or medium. It is defined as the product of the density (p) and sound velocity (V) within a given material.

IMPEDANCE = DENSITY X VELOCITY, or Z = pV

where: Z = IMPEDANCE

p = DENSITY

V = VELOCITY

From what is stated above, could we determine the acoustical impedance or sound resistance of a material (medium) if we knew its characteristic density and sound velocity?

No . . . . Page 2-18

Yes . . . . Page 2-19

Your choice "No" is the wrong answer. The acoustical impedance or sound resistance of a given material <u>can</u> be determined if the material's density and sound velocity characteristics are known. Remember the definition? Acoustical impedance is the PRODUCT of the DENSITY and VELOCITY within the material (medium). In other words IMPEDANCE = DENSITY X VELOCITY.

Turn to page 2-19 and continue.

[redacted]

From page 2-17

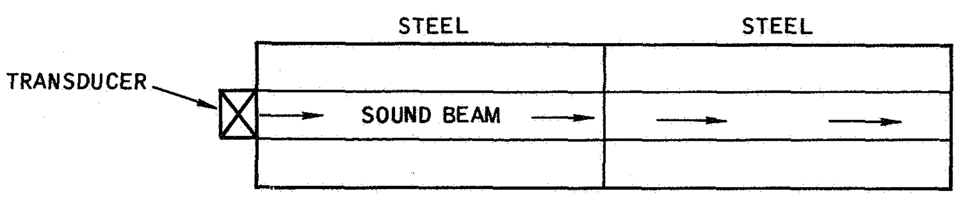
Good. "Yes" is the correct answer. The acoustical impedance or sound resistance of a material can be determined by multiplying the material's density and velocity.

The impedance values for typical materials (media) are listed below along with velocity and density. Note the difference in impedance values for the media (materials) listed.

MATERIAL	IMPEDANCE ($GRAM/CM^2$ - SEC)	VELOCITY (CM/SEC)	DENSITY ($GRAM/CM^3$)
AIR	0.000033×10^6	0.33×10^5	0.001
WATER	0.149×10^6	1.49×10^5	1.00
ALUMINUM	1.72×10^6	6.35×10^5	2.71
STEEL	4.56×10^6	5.85×10^5	7.8

As you can see, the acoustical impedance varies from one material (medium) to another, depending on the material's specific velocity and density characteristics. Air has a very low impedance, with water being relatively higher. Aluminum and steel have still higher impedances.

Now if we transmit sound energy into two pieces of identical steel, we find that the sound will move with the same velocity through both pieces. We can also say the two pieces of steel are matched and have an impedance ratio of 1 to 1.



VELOCITY REMAINS CONSTANT

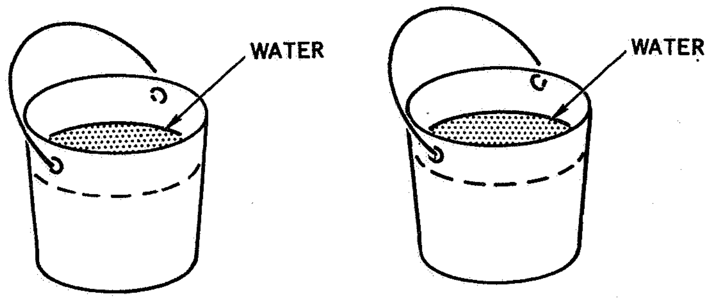
Could we say the same thing is true if we place "water in touch with water"?

No . . . . Page 2-20

Yes . . . . Page 2-21

You apparently do not have the idea yet. You should have said "Yes". If we place water in contact with water, the sound velocity through the water remains constant and the impedance ratio is 1 to 1.

For example, we have two identical buckets of water.



Doesn't the water in each bucket have the same density and sound velocity? Yes. Isn't the acoustical impedance the same for the water in both buckets? Yes.

Therefore the acoustical properties of the water in one bucket are the same as for the water in both buckets. The impedance ratio is 1 to 1.

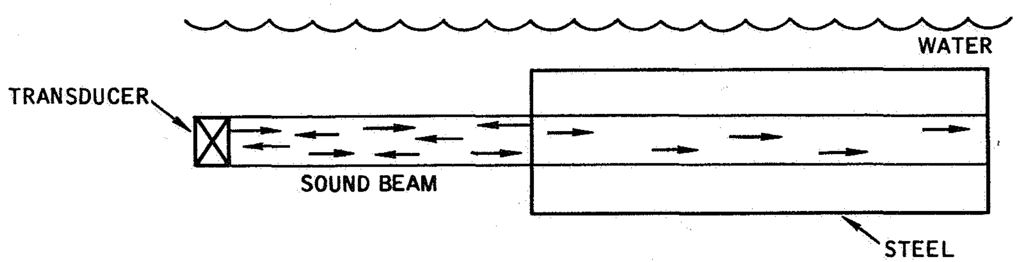
Turn to page 2-21.

From page 2-19

Fine. You're on the right track. "Yes" is the correct answer. The velocity will remain the same through "water in touch with water" and the impedance ratio will be 1 to 1.

In the preceding examples, we used steel versus steel and water versus water to determine that sound velocity is constant for the given medium (material) and varies from one medium (material) to another.

Now let's place water in contact with steel and transmit a sound beam through the media. Note what happens.



The water has one impedance value and steel another. We now have an impedance mismatch. The ratio is no longer 1 to 1. Anything greater or less than a ratio of 1 to 1 is less than ideal. Therefore not all of the energy will transfer from the water to the steel. A large portion of the sound beam will reflect back towards the transducer.

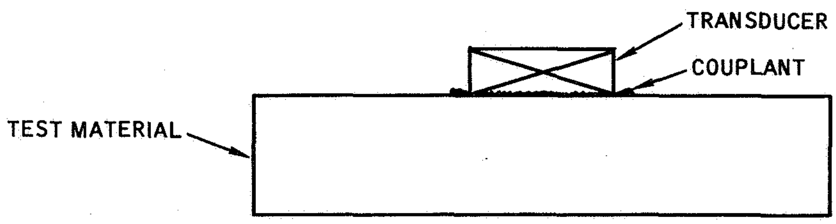
Which of the following conditions provides the better impedance ratio?

A water-to-steel impedance ratio . . . . Page 2-22

An air-to-steel impedance ratio . . . . Page 2-23

You're right. The impedance of water comes closer to the impedance of the steel; therefore, we have a better impedance ratio. Air is a poor medium for transferring ultrasonic vibrations into liquids or solids.

A transducer is also considered a medium and has a characteristic acoustical impedance like other materials. And, to minimize or reduce any impedance mismatch that exists between the transducer and the test material, we must put something between it and the test material. This something is called a "couplant". A couplant may be a solid, semisolid, or a liquid. The more common examples are water, glycerin, oil, and grease. Sometimes foils, rubber, and waxes or cements are used.



When we use a couplant between the transducer and the surface of the test material, we are in effect doing two things: (1) removing air between the transducer and the material, thus reducing the impedance ratio between the transducer and the test material and, (2) providing a medium to transfer the transducer vibrations to the test material.

From this, could we say a couplant couples the transducer to the test material?

Yes . . . . Page 2-24

No . . . . Page 2-25

Wrong. You should have picked the water-to-steel impedance ratio as the better ratio. Air has a very low impedance in comparison with water or steel. Remember that the closer the impedance values of the different media match, the more sound will be transferred from one medium to another.

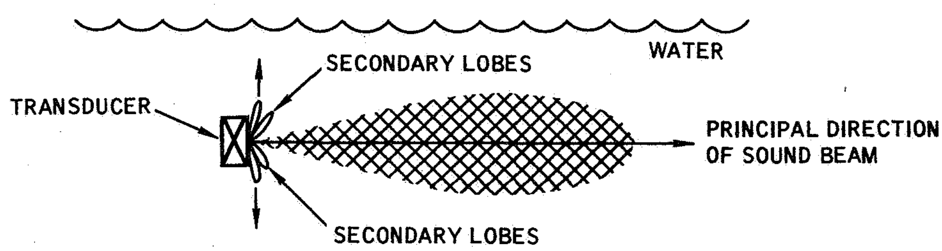
Turn to page 2-22.

[redacted]

From page 2-22

Right. You chose the correct answer. A couplant is used to couple the transducer to the test material. It provides a sound path and removes air between the transducer and test material. We also find that the closer the couplant impedance matches that of the test material, the better the sound transfer.

Up till now, we have assumed the useful width of the sound beam emitted from a transducer is the same width as the transducer. Well this is not quite true. For example, let's place a transducer under water and transmit a sound beam into the water as shown below.



The above illustration shows a typical example of how a sound beam radiates from a transducer. Note that most of the ultrasonic energy is bunched along the centerline of the beam. Also note that secondary or side lobes form at the transducer face and radiate away from the principle direction of sound travel. These secondary or side lobes represent areas of high and low intensities at the edge of the beam.

Could we say the secondary or side lobe effect increases the useful width of the transducer?

No . . . . Page 2-26

Yes . . . . Page 2-28

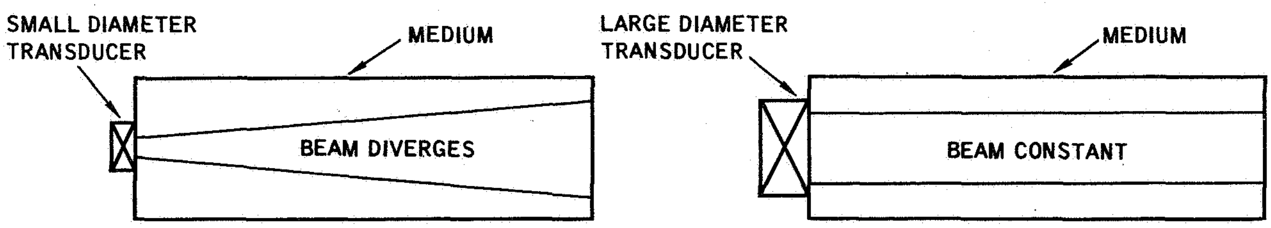
Your answer "no" is not correct. A couplant <u>does couple</u> the transducer to the test material. It reduces the impedance ratio that would normally exist between the transducer and the test material and removes air. The couplant ensures maximum transfer of sound into the test material by coupling the transducer to the material.

Turn to page 2-24.

From page 2-24

You are right. The secondary or side lobe effect does <u>not</u> increase the useful width of the transducer. The opposite is true. Because of the secondary lobes, we find the useful width of a transducer is always less than the transducer's physical width.

In views A and B below, we see two different size transducers coupled to a medium. Notice how transducer diameter affects divergence (beam spread) within a medium.



The smaller diameter transducer has a greater beam spread than the larger diameter transducer. Thus we can say a transducer's diameter has a definite influence on the sound beam transmitted through a medium.

Recall that if we change the transducer's vibrating frequency, the beam spread within a medium will also change. Divergence is inversely proportional to frequency. That is a high frequency transducer has a narrow and relatively constant diameter sound beam where a low frequency transducer has a spreading or divergent beam.

Select the statement that is true.

Beam divergence can be reduced by increasing transducer frequency or by using a larger diameter transducer . . . . Page 2-27

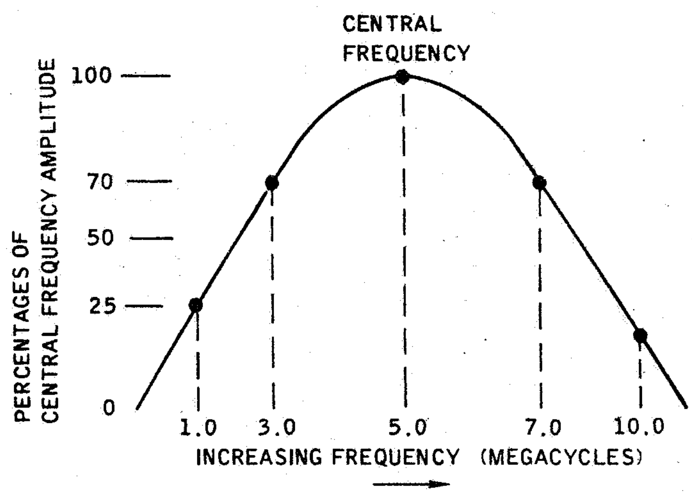
Beam divergence can be reduced by reducing transducer frequency or by using a smaller diameter transducer . . . . Page 2-29

From page 2-26

Correct! Beam divergence can be reduced by increasing transducer frequency or by using a larger diameter transducer.

Each transducer has a rated or central frequency at which it is designed to vibrate the easiest, for example 5.0 megacycles, 10.0 megacycles, etc. A transducer will also respond over a band of frequencies depending on its own characteristic response curve. This band of frequencies is known as the bandwidth.

The graph below illustrates the relationship between the central frequency amplitude and bandwidth. In this case the transducer's central frequency is 5.0 megacycles. Amplitude is expressed in percentages of the central frequency's amplitude.



All frequencies having an amplitude within 70 percent of the central frequency's amplitude are within the band. Therefore in the example, the bandwidth is...

all the frequencies between 3.0 and 5.0 megacycles . . . . Page 2-30

all the frequencies between 5.0 and 7.0 megacycles . . . . Page 2-31

all the frequencies between 3.0 and 7.0 megacycles . . . . Page 2-32

From page 2-24

Your answer "Yes" is not correct. The secondary or side lobes do not increase the useful width of the transducer. In fact the opposite is true.

Recall that the secondary or side lobes formed at the face of a transducer are areas of high and low intensities. For this reason, they tend to reduce the useful width of the transducer.

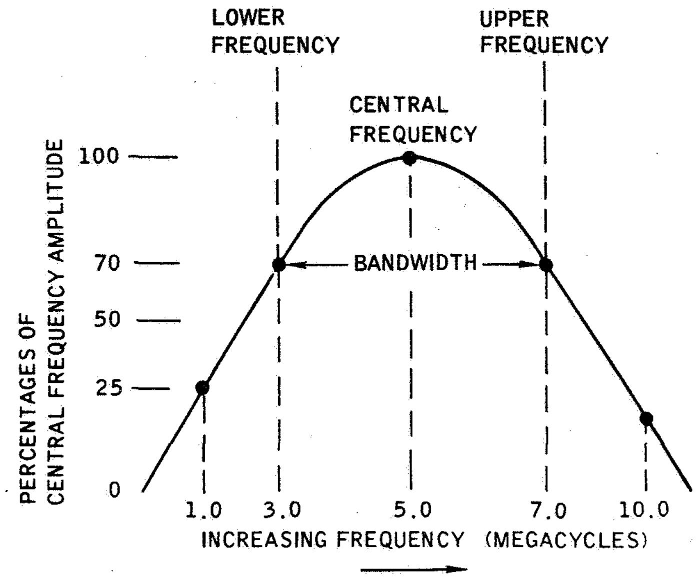
Turn to page 2-26.

[redacted]

Wrong. Beam divergence can be reduced by INCREASING not decreasing transducer frequency. You can also use a LARGER diameter transducer to reduce beam divergence or beam spread.

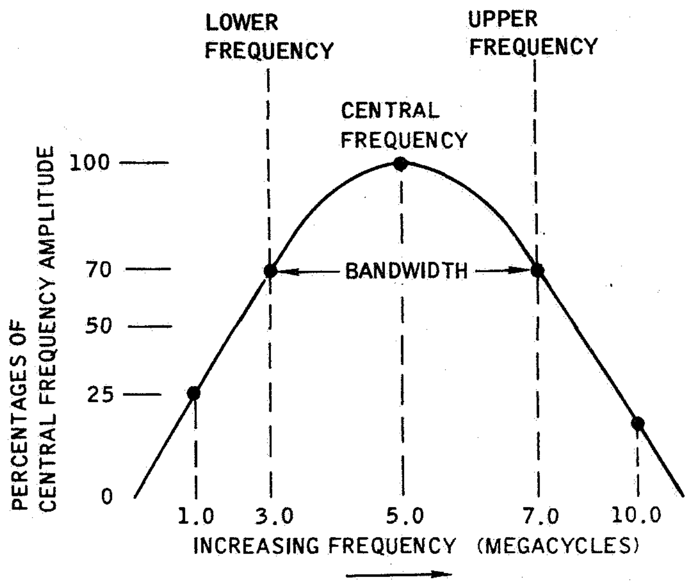
Turn to page 2-27.

You're not quite right. Look at the graph again. Aren't the frequencies between 5.0 and 7.0 megacycles also above the 70 percent minimum amplitude? Yes. Therefore the bandwidth shown on the graph extends from 3.0 megacycles to 7.0 megacycles.



Turn to page 2-32.

You do not have the idea yet. All frequencies between 5.0 and 7.0 megacycles is not the correct answer. Don't the frequencies between 3.0 and 5.0 megacycles also have an amplitude above the 70 percent minimum? Yes. Therefore, the bandwidth shown on the graph extends from 3.0 to 7.0 megacycles.



Turn to page 2-32.

From page 2-27

Excellent. The bandwidth shown on the graph is 3.0 to 7.0 megacycles. You learned that a transducer will vibrate over a band of frequencies. And bandwidth is determined by the transducer's central frequency amplitude.

Turn to the next page for a review.

From page 2-32

1. A device which converts energy from one form to another is known as a t____________.

6. divergence
   beam spread

7. Beam intensity (decreases) (increases) ____________ as the distance from the center of the beam increases.

12. density
    velocity

13. Velocity (remains the same) (changes) ____________ from one medium to another.

18. less than

19. A small diameter transducer has (more) (less) ____________ beam divergence than a larger diameter transducer.

1. transducer

2. In ultrasonic testing, the terms transducer and cry__________l are often used interchangeably.

7. decreases

8. The n_____r zone is that part of a sound beam closest to the transducer with the f_____ zone beyond.

13. changes

14. Impedance mismatch between mediums is known as the im_______ r_____o.

19. more

20. Frequency also affects beam characteristics. A (low) (high) _________ frequency transducer has a spreading or divergent beam.

2. crystal

3. A piez________c transducer (crystal) can convert electrical energy to mechanical energy; or mechanical energy to electrical energy.

8. near
far

9. The (near) (far) ________________ zone is the zone of irregular intensities.

14. impedance ratio

15. The impedance ratio between mediums can be improved by using a c__________t.

20. low

21. A high frequency transducer has a (wide) (narrow)________________ and relatively constant diameter beam.

3. piezoelectric

4. A piezoelectric crystal (transducer) can both send and re_________ effects.

9. near

10. The gradual loss of energy as a beam travels through a material (medium) is known as att________tion.

15. couplant

16. Water, glycerin, oil, and grease are the most common c__________s. Gaseous mediums, for example air, make very p_______ couplants.

21. narrow

22. A transducer will respond to a band of frequencies dependent on its central frequency a_________. This band of frequencies is known as the b____ w_______.

4. receive

5. An ultrasonic sound beam is a small, narrow beam of mec__________ en__________y.

10. attenuation

11. The sound resistance of a medium is identified by the term acou__________l im__________ .

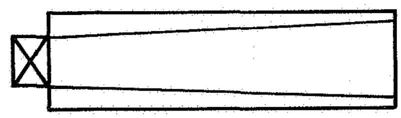
16. couplants
poor

17. Couplants ensure maximum energy t__________ between mediums.

22. amplitude
bandwidth

23. This completes the review of Chapter 2. Turn to page 3-1.

5. mechanical energy



6. The tendency of a beam of energy to spread is known as div__________e or be________ sp__________d.

Return to page 2-33, frame 7

11. acoustical impedance

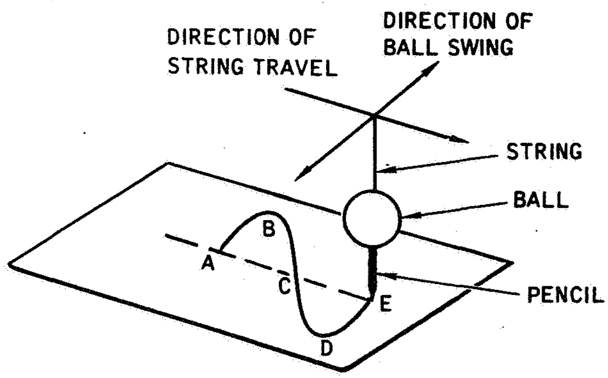
12. Acoustical impedance is the product of the den____ and ve________y within a material (medium).

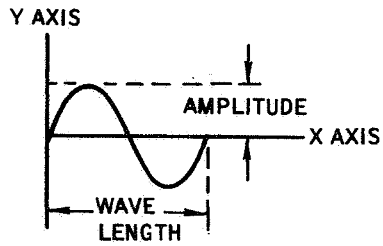
Return to page 2-33, frame 13

17. transfer or transmission

18. Because of the secondary or side lobe effect at the face of a transducer, the useful width of the transducer is (the same as) (less than)________________ the transducer's physical width.

Return to page 2-33, frame 19





SIMPLE HARMONIC WAVE

From Chapter 1, recall the example of the swinging ball with the pencil attached to it. As we moved the top end of the string horizontally, the pencil drew a curve and from this we learned that one complete swing from A through E is a cycle. The pattern we got for one complete cycle also illustrates a simple harmonic wave.

The term "wave" as applied to ultrasonic testing refers to the mechanical vibrations being transmitted through a medium. It is the ultrasonic sound or beam emitted by the transducer. In fact, we find the terms "wave", "beam", and "sound" are used interchangeably in ultrasonics.

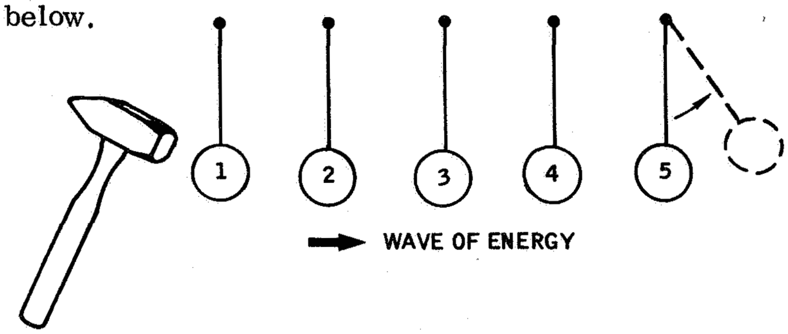
From this, can we say a wave is energy moving through a medium?

Yes . . . . Page 3-2

No . . . . Page 3-3

You're right. A wave is energy moving through a medium. And this movement is the result of mechanical vibrations within a medium.

We find that in ultrasonic wave travel or propagation, there is a successive displacement of a medium's elements or particles. The medium being elastic has a restoring force which tends to bring each element back to its original position. Since all such media also possess inertia, we find the element or particle will overshoot its original position to a point beyond. From this second point, it returns to its starting position, about which it continues to bounce back and forth with constantly diminishing amplitude. As the wave moves through the medium, each particle is displaced a little later than its neighbor nearer to the source of vibration and earlier than its neighbor more distant from the source. To understand this, let's use a row of balls suspended from strings as shown below.



If we strike ball 1 with a hammer the energy we give ball 1 will propagate through the series of balls and displace ball 5. This action can be defined as a wave. Balls 1 through 4 will, after transmitting the wave to the next ball, continue to vibrate with diminishing amplitude. Ball 5 will swing out and then back striking ball 4, propagating a return wave back toward ball 1. Though the actual movement of each individual ball in the chain is extremely small, the effect of ball movement is very pronounced. This is basically the action set up in a medium when using ultrasonic test equipment.

Can we say the transmission of ultrasonic sound waves depends on particle motion within a medium for wave propagation?

No . . . . Page 3-4

Yes . . . . Page 3-5

From page 3-1

"No" is the wrong answer. You should have said "yes". We can say that a wave is energy moving through a medium.

Recall that when we drop something into water, a series of waves are formed on the surface of the water which radiate away from the impact point in an ever expanding circle. Aren't the waves the result of vibrations within the water? Yes. Can't we then say these waves represent energy in motion, or energy moving through a medium? Yes.

Turn to page 3-2.

From page 3-2

"No" is the wrong answer. Propagation of ultrasonic sound waves <u>does</u> depend on particle motion within a medium.

For example, let's use a length of rope secured at one end to define wave propagation. If we stretch the rope out and shake the loose end up and down, we can produce a series of waves that will travel along the rope toward the secured end. Doesn't this wave action depend on the up and down motion of the rope? Yes. Can't these up and down motions be considered as vibrations? Yes. It is the ability of particle vibrations within a medium to transfer their energy of motion to adjacent particles that gives use to a wave or beam of energy.

Turn to page 3-5.

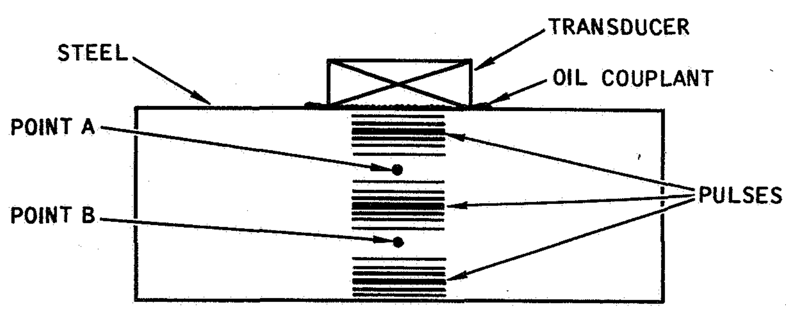
From page 3-2

Correct. The transmission of ultrasonic sound waves does depend on particle motion within a medium for wave propagation.

Now let's recall the formula $\lambda = v/f$. wavelength $= \frac{\text{velocity}}{\text{frequency}}$. From the formula, we learned that we can determine the wavelength of a wave by dividing the wave's velocity by its frequency. We found we could increase wavelength by reducing the frequency and decrease the wavelength by increasing frequency. We also learned that the wave velocity for a given medium (for example water, steel, aluminum) remains constant but varies from one medium to another. Velocity is a fixed value that is dependent upon the elasticity and density of the given medium.

Velocity can also be defined as the distance a wave will propagate through a medium in a given time, usually fractions of a second. In other words, velocity is the speed of a vibration or wave in moving from point to point.

The illustration below shows a transducer coupled to a piece of steel. Let's visualize a series of wave pulses being propagated through the steel.



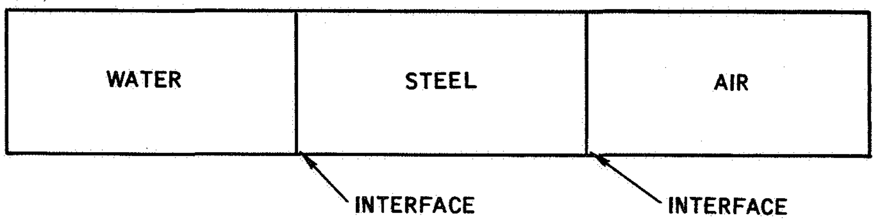
The wave speed (velocity) at point B will be...

The same as at point A . . . . Page 3-6

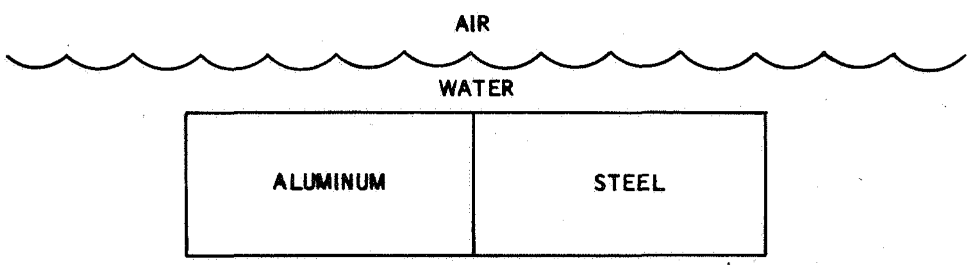
Less than at point A . . . . Page 3-8

Right! The wave speed or velocity at point B is the same as at point A. You remembered that wave speed remains constant through a given medium.

Recall that waves traveling through a medium of a given acoustical impedance are also reflected when they encounter a medium of another acoustical impedance. And the amount of reflection between the two media is dependent on the acoustical impedance ratio. The surface at which this reflection occurs is called an "interface".



An interface is the boundary between two materials or media which are in contact with each other and have a different acoustical impedance.

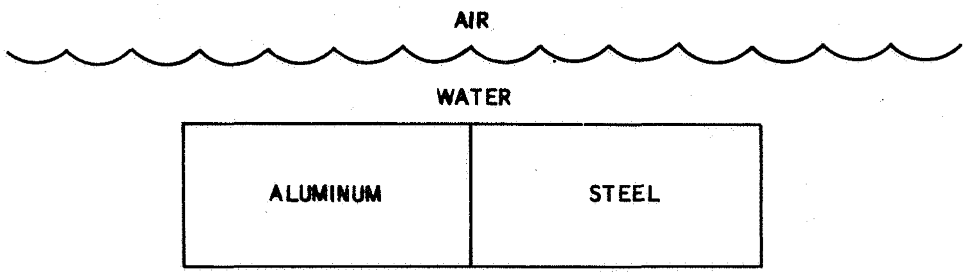


The illustration above shows a block of aluminum and a block of steel in contact with each other and submerged in water. Which of the material surfaces can be considered an interface?

Only the surfaces of the blocks which are in contact with each other . . . . Page 3-7
All of the surfaces . . . . Page 3-9

From page 3-6

You did not select the better answer. It is true that the surfaces between the aluminum and steel blocks meet the requirements of an interface; but . . . don't the other surfaces shown in the illustration also meet the requirement? Let's take another look at the example.



Don't we have a difference in impedance between the air and water, the water and aluminum, and the water and the steel? Yes, of course. Each of these surfaces meets the requirements of an interface. Again, an interface is defined as a boundary between two materials or media of different acoustical impedance.

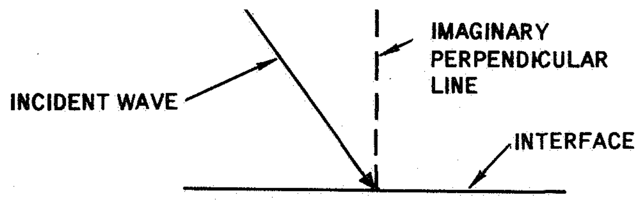
Turn to page 3-9.

You are not right. Wave speed (velocity) does not decrease as the energy moves through a given material. (The loss of energy as it moves through a material is independent of velocity.) Remember that velocity is a fixed value for a given material but varies from one material to another. Therefore, the wave speed (velocity) at points A and B in the preceding example are the same.

Turn to page 3-6.

Very good. You chose the better answer. All of the surfaces shown in the example meet the requirements of an interface. You remembered that an interface is the boundary between any two materials of different acoustical impedance ... be it aluminum-to-steel, water-to-aluminum, water-to-steel, or air-to-water.

A beam of energy approaching an interface is referred to as an "incident wave." And the angle at which the wave strikes the interface in relation to an imaginary line drawn perpendicular to the interface is known as the "angle of incidence."



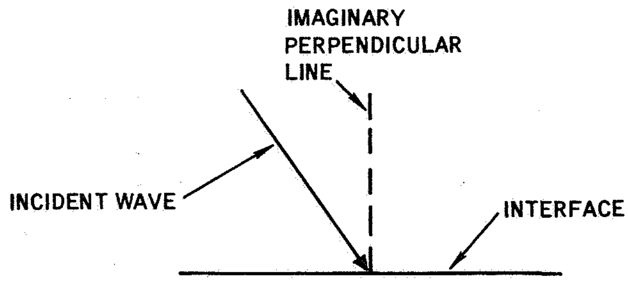
ANGULAR INCIDENCE

From the above statements, can we vary an incident wave's angle of incidence from the perpendicular direction of travel?

No . . . . Page 3-10

Yes . . . . Page 3-11

Wrong. The angle of incidence <u>can</u> be varied from the perpendicular direction of travel. Recall the example depicting "angular incidence."



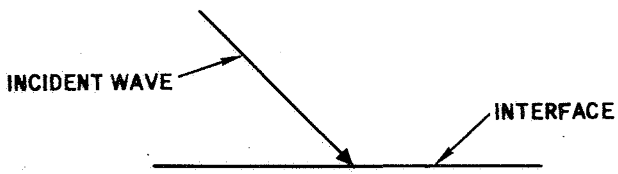
ANGULAR INCIDENCE

Isn't the incident wave's direction of propagation shown in other than the perpendicular direction? Yes. Remember - the term "incident wave" describes a wave that is approaching an interface. And the angular variation of this wave from the perpendicular is known as the <u>angle of incidence.</u>

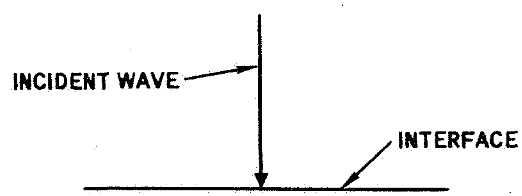
Turn to page 3-11.

Right. We can vary an incident beam's angle of incidence from the perpendicular direction of travel. Later on you will learn the importance of being able to angulate a sound beam.

There is also another term which may be used to describe the perpendicular propagation of an incident wave ... "normal incidence." An incident wave is said to have normal incidence when its direction of progagation is perpendicular to an interface. The angle of incidence is zero.



EXAMPLE A



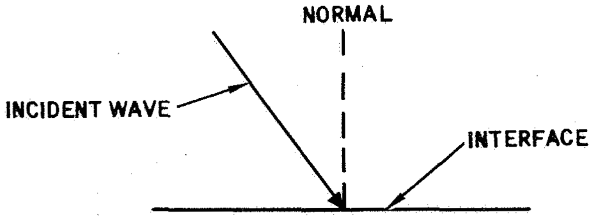
EXAMPLE B.

Which of the above examples illustrates normal incidence?

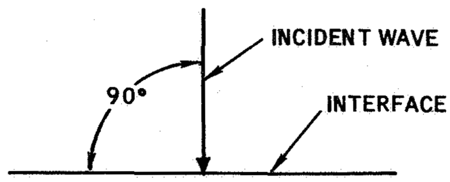
Example A . . . . Page 3-12

Example B . . . . Page 3-13

Incorrect. Example B shows <u>normal incidence</u>, not example A (your choice). Let's take a look at the two examples.



EXAMPLE A



EXAMPLE B

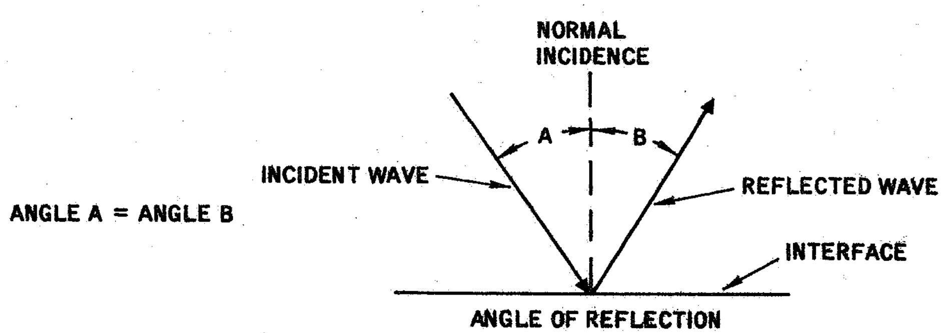
Doesn't example A show the incident wave's direction of propagation other than perpendicular to the interface? Yes. Remember that to identify a wave's angle of incidence as "normal," it must be <u>perpendicular</u> to the interface. Only example B shows the incident wave normal to the interface.

Turn to page 3-13.

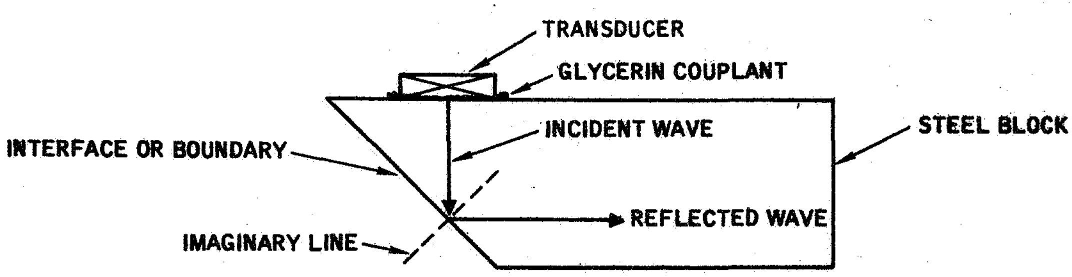
From page 3-11

Right! Example B represents the sound wave having normal or perpendicular incidence.

Some of the wave energy striking an interface will be transmitted through the interface and some of the energy will be reflected back toward its source. The amount of reflected energy depends on the acoustic impedance ratio between the media involved. If we alter the angle of incidence to other than normal incidence, the reflected wave angle will also change an equal amount. Remember - the "angle of reflection" at an interface or boundary always equals the "angle of incidence."



This relationship between the incident wave angle and the reflected wave angle is also true within a material as illustrated below.



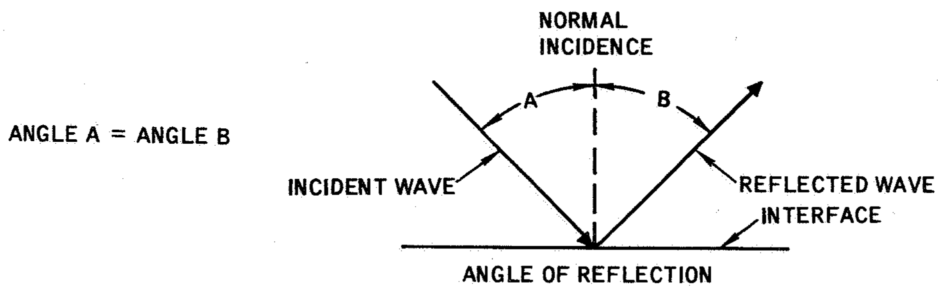
Now for example, let's say the incident wave's angle of propagation is 10 degrees from normal incidence. The reflected wave's angle of propagation will be ...

10 degrees from the interface . . . . .Page 3-14

10 degrees from normal incidence . . . . .Page 3-15

From page 3-13

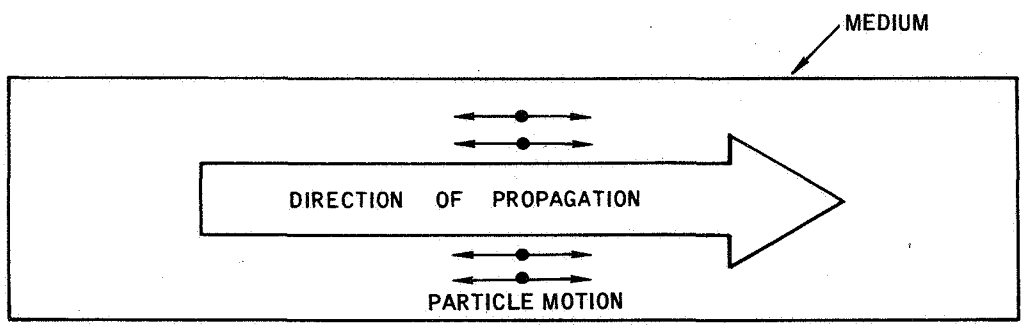
"No" is not the correct answer. The reflected wave's angle of propagation will NOT be 10 degrees from the interface but 10 degrees from NORMAL INCIDENCE. Recall that the angle of the reflected wave always equals the angle of the incident wave with reference to normal incidence.



Turn to page 3-15.

Excellent! The reflected wave's angle of propagation would be 10 degrees from normal incidence. The angle of reflection equals the angle of incidence with reference to normal incidence.

There are many modes of ultrasonic vibrations which will travel through solids. The modes most widely used in ultrasonic testing are: longitudinal, shear, surface, and plate waves. Each mode or type causes a specific movement in the elements of a medium.



LONGITUDINAL WAVES

Longitudinal (compression) waves are waves in which the particle vibrations are restrained to a back and forth motion in the direction of wave propagation. They have a high velocity in most materials and will travel through liquids, solids, and gases. Longitudinal waves are also known as compressional or L waves.

Is the following statement true or false? Longitudinal waves produce vibrations which are perpendicular to the motion of the sound.

True . . . . Page 3-16

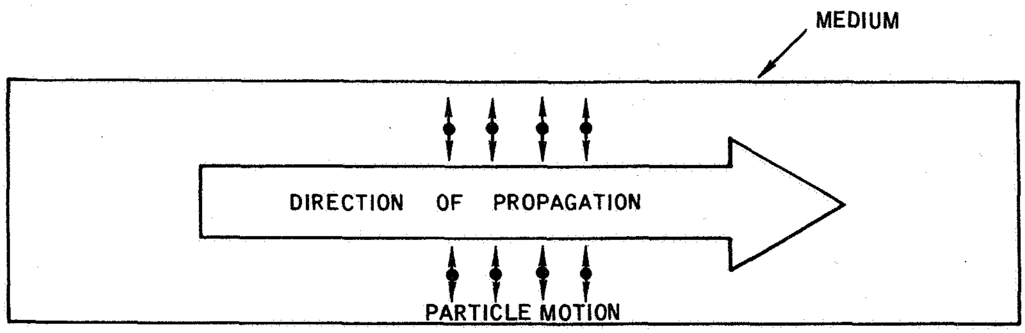
False . . . . Page 3-17

Wrong. "False" is the correct answer. Longitudinal waves produce vibrations which are in the SAME DIRECTION as the motion of sound. We can illustrate this characteristic by alternately stretching and releasing a rubber band. The particles move back and forth in the same direction as the operating forces.

Turn to page 3-17.

From page 3-15

Very Good! "False" is the correct answer. Longitudinal waves produce vibrations in the same direction (not perpendicular) to the motion of the sound.



SHEAR WAVES

A wave having particle vibrations perpendicular to the direction of wave motion is called a "shear" or "transverse" wave. A shear wave may also be known as an S wave. The velocity of shear waves is approximately one-half that of longitudinal waves. Because of this lower velocity, the wavelength of shear waves is much shorter than that of longitudinal waves. Another characteristic we should remember is that shear waves will not travel through liquids or gases, since there is little or no elasticity to shear in such media.

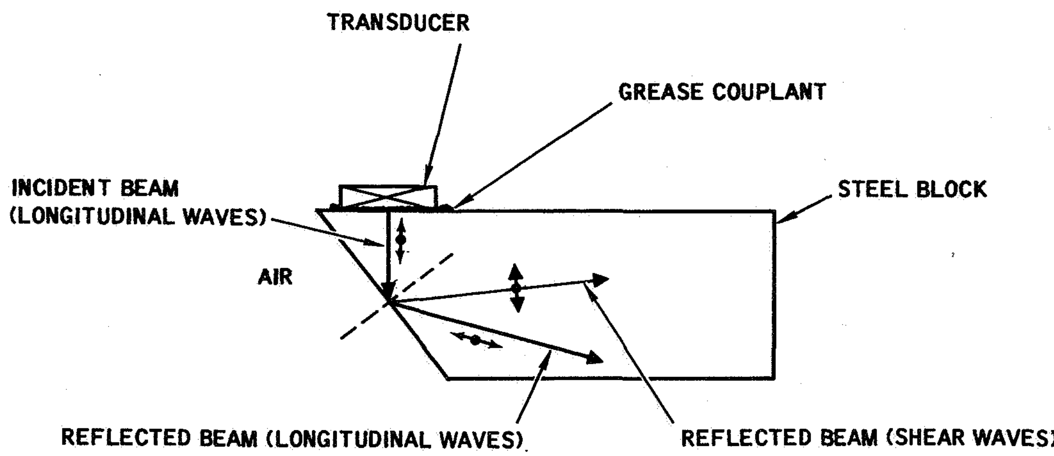
Can we say shear waves propagate with particle motion transverse to the direction of wave travel?

Yes . . . . Page 3-18

No . . . . Page 3-20

Right. We can say shear waves propagate with particle motion transverse to the direction of wave travel.

When a sound beam strikes an interface between two materials having different acoustic impedances and the direction of beam travel is other than normal incidence, some energy may be converted to other modes of vibrations. A simple example of "mode conversion" is shown in the steel block below.



Since a negligible amount of energy leaves the steel because of the extreme impedance mismatch of the steel/air interface, the reflection is total. However, to satisfy all continuity conditions, two reflected beams exist. One beam consists of longitudinal (compression) waves and the second of shear (transverse) waves. Particle motion (⟵•⟶) is in the direction of propagation for the longitudinal waves and at right angles for shear waves.

Mode conversion takes place when a sound beam hits an interface between two different media at an angle:

Normal to the interface . . . . Page 3-19

Other than 90 degrees to the interface . . . . Page 3-21

From page 3-18

Wrong. Mode conversion takes place when a sound beam hits an interface between two different media at an angle OTHER THAN 90 DEGREES (NORMAL) TO THE INTERFACE (not at an angle normal to the interface).

Mode conversion is defined as the transforming of a wave into other modes because of an impedance mismatch at an interface and the direction of incident wave travel being other than at normal incidence.

Turn to page 3-21 and continue.

Your selection "No" is incorrect. Shear waves do propagate with particle motion transverse (perpendicular) to the direction of wave travel.

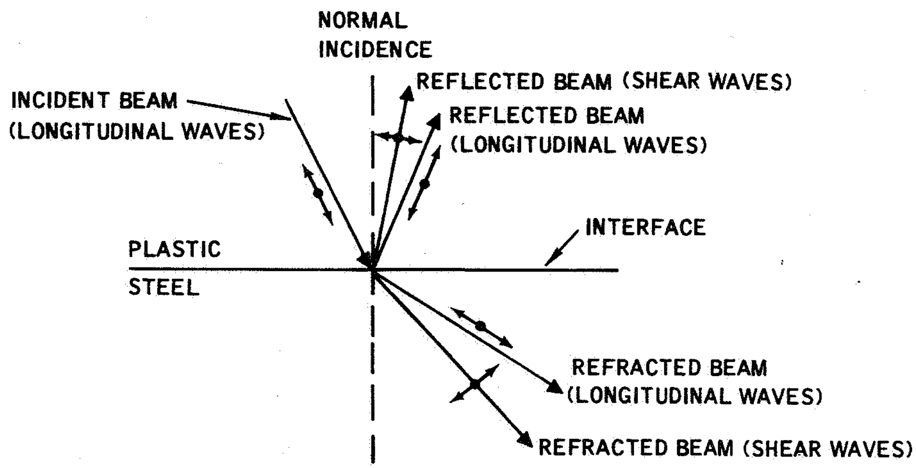
Shear wave propagation can be compared to a rope stretched taut between two points. If we shake one end of the rope up and down, we can see the shaking movement will travel as a wave along the full length of the rope and return. As the rope flexes, the individual elements of the rope move in a direction at right angles to the direction of wave motion. These transverse movements are similar to the particle vibrations in shear waves.

Turn to page 3-18.

From page 3-18

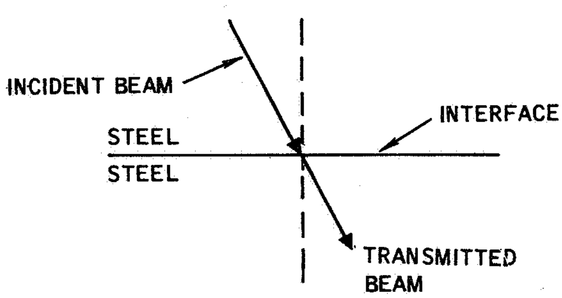
Good. You selected the right answer. Mode conversion takes place when a sound beam hits an interface between two different media at an angle other than 90 degrees (normal) to the interface.

The following illustration shows another example of mode conversion. In this case the incident beam is traveling at an angle through plastic and striking the steel. Because of the better impedance ratio of the plastic/steel interface, a portion of the incident beam's energy will be transmitted as shown.

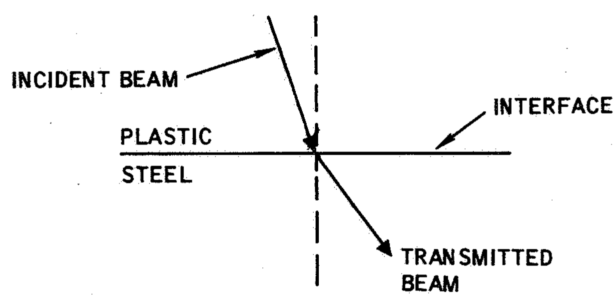


In addition to mode conversion, ultrasonic waves which cross an interface or boundary at a slant undergo abrupt changes in direction of travel when the velocity of propagation is different in the two media. This bending is called "refraction." The "angle of refraction" is the angle formed between a refracted ultrasonic beam as it enters the second medium and a line drawn perpendicular to the interface.

Which of the following examples illustrates refraction?



EXAMPLE Y



EXAMPLE Z

Example Y . . . . Page 3-22

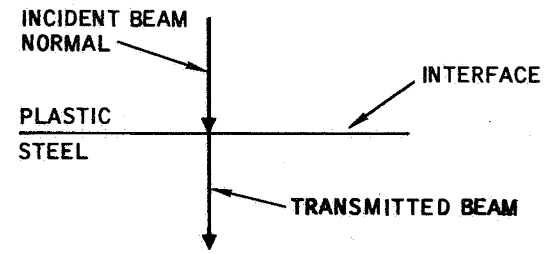
Example Z . . . . Page 3-23

Wrong. You should have selected "example Z" as the example most nearly showing refraction.

Refraction is the change in a beam's direction of propagation after passing through an interface. The conditions required for refraction are: (1) the incident beam must be traveling at other than normal incidence and (2) there must be a difference in velocity between the materials making up an interface (for example plastic-to-steel).

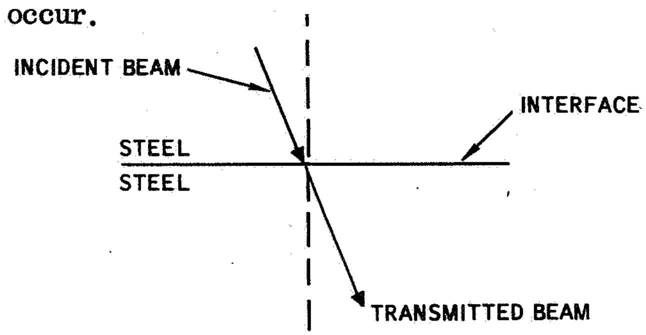
If the angle of incidence is normal to an interface as shown in "example X", below, no refraction will take place regardless of the materials involved.

EXAMPLE X



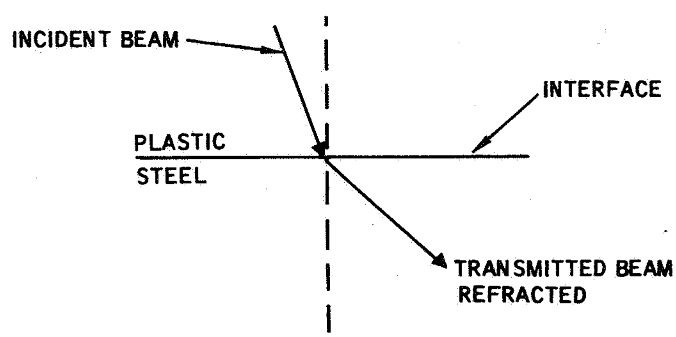
If the angle of incidence is other than normal as shown in "example Y" and the media making up the interface have the same characteristic velocity (for example steel-to-steel), no refraction will occur.

EXAMPLE Y



If the angle of incidence is other than normal and the media making up the interface have different velocities as shown in "example Z", we will have refraction.

EXAMPLE Z



Turn to page 3-23.

From page 3-21

Excellent! "Example Z" does more nearly illustrate refraction.

The angular relationships of waves within a medium can be determined for both longitudinal and shear waves by "Snell's Law". Snell's Law is defined by the equation:

$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2}$$

ϕ is called PHI

where ϕ_1 = angle of incidence

V_1 = velocity of sound in first medium

ϕ_2 = angle of refraction

V_2 = velocity of sound in second medium.

The value "sin ϕ" (pronounced sign) is obtained from a table of trigonometric values. The value of "sin ϕ" is always smaller than one; the largest value occuring when ϕ (the angle) is 90 degrees from normal incidence.

The characteristic velocities for different wave modes in materials are obtained from tables listing the acoustic properties of materials.

As an example, let's calculate the angle of refraction ϕ_2 for a longitudinal wave passing through a water-to-steel interface. The following numbers are substituted for ϕ_1, V_1, and V_2:

10 degrees = angle of incidence (ϕ_1)

1.49×10^5 cms/sec = longitudinal wave velocity in water (V_1)

5.85×10^5 cms/sec = longitudinal wave velocity in steel (V_2)

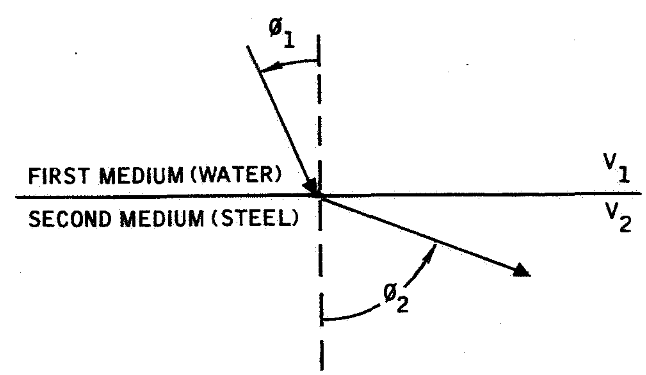
$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2}$$

$$\sin \phi_2 = \frac{V_2(\sin \phi_1)}{V_1}$$

$$\sin \phi_2 = \frac{1.012}{1.49}$$

$$\sin \phi_2 = 0.6791$$

$$\phi_2 = 42° 46'$$



Turn to page 3-24.

In a similar manner, we can find the angle of refraction ϕ_2 for transmitted shear waves by substituting the shear wave velocity in steel for the longitudinal velocity in steel.

10 degrees = angle of incidence (ϕ_1)
1.49×10^5 cms/sec = longitudinal wave velocity in water (V_1)
3.23×10^5 cms/sec = shear wave velocity in steel (V_2)

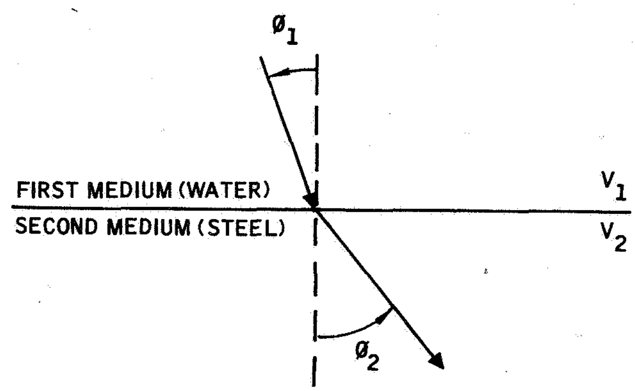
$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2}$$

$$\sin \phi_2 = \frac{V_2 (\sin \phi_1)}{V_1}$$

$$\sin \phi_2 = \frac{0.559}{1.49}$$

$$\sin \phi_2 = 0.3684$$

$$\phi_2 = 21° 37'$$



Snell's Law is used to determine a wave's ...

Reflection angle . . . . Page 3-25

Refraction angle . . . . Page 3-26

From page 3-24

You are incorrect. Snell's Law is used to determine a wave's REFRACTION ANGLE (not the reflection angle). We use the formula...

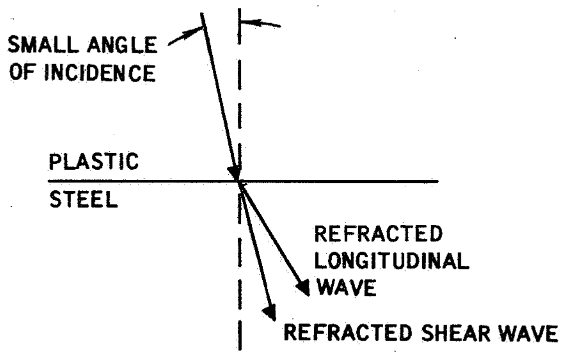
$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2} \quad \text{(Snell's Law)}$$

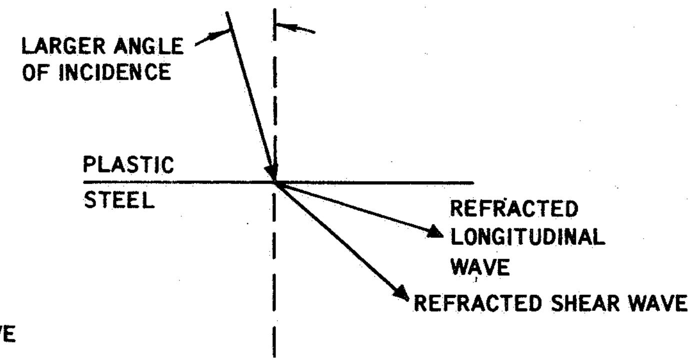
to find the angular relationships of a sound beam traveling through two materials having different velocities.

Turn to page 3-26.

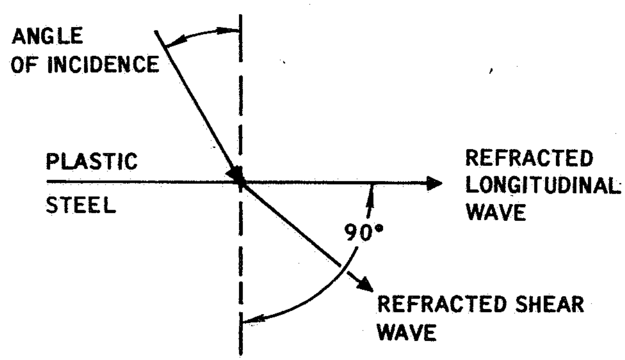
Right! Snell's Law is used to determine a wave's refraction angle within a medium. The law can also be used to determine the angle of incidence if the angle of refraction is known.

In calculating angles, we notice that slight angulations of an incident beam produce relatively large angles of refraction. As the angle of incidence is increased, the angle of refraction increases.





When the refraction angle of a longitudinal wave reaches 90 degrees, the wave emerges from the second medium and travels parallel to the interface or surface. The angle of incidence at which the refracted longitudinal wave emerges is called its "critical angle." For greater angles of incidence, the longitudinal wave mode is totally reflected and no longer exists.



Can we define the longitudinal wave critical angle as the angle of incidence which results in 90-degree refraction of the longitudinal wave mode?

No . . . . Page 3-27

Yes . . . . Page 3-28

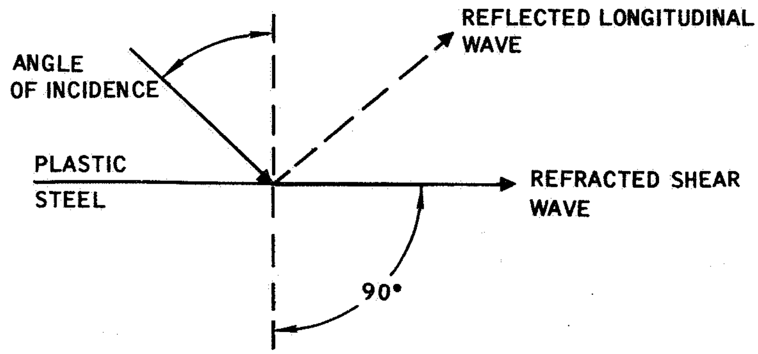
"No" is not the right answer to the question. We CAN define the longitudinal wave critical angle as the angle of incidence which results in 90-degree refraction of the longitudinal wave mode. We find the longitudinal wave mode traveling along the surface of the material.

Turn to page 3-28.

From page 3-26

Good! The longitudinal wave critical angle <u>is</u> the angle of incidence which results in 90-degree refraction of the longitudinal wave mode.

Now if we keep increasing the angle of incidence till the angle of refraction for the shear wave mode is 90 degrees, we have what is known as the critical angle of incidence for the shear waves. The shear wave mode emerges and travels parallel to the interface or surface.



For incident beam angles beyond this second critical angle, we have total reflection. Both the longitudinal and shear wave modes are reflected.

By <u>total reflection</u>, we mean no incident beam energy is being transmitted...

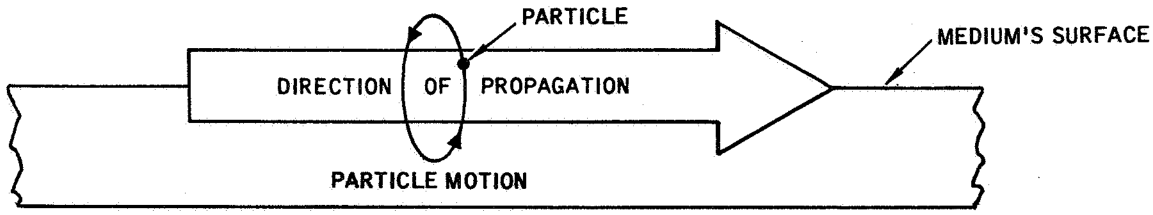
Through the interface . . . . Page 3-29

Through the second medium . . . . Page 3-31

From page 3-28

Very Good! Total reflection means no incident beam energy is being transmitted through the interface.

When the incident beam is at its second critical angle (shear waves traveling parallel to the surface), a third wave form is developed. This wave is called a "surface" or "Rayleigh" wave. Its characteristic particle motion is elliptical.



SURFACE WAVES

Surface (Rayleigh) waves travel only on the surface of a solid material, their penetration being about one wavelenth. And their velocity is slightly less than that of shear waves. We also find surface waves can be dampened out by placing an object such as your finger, water, or grease on the surface over which the waves are traveling.

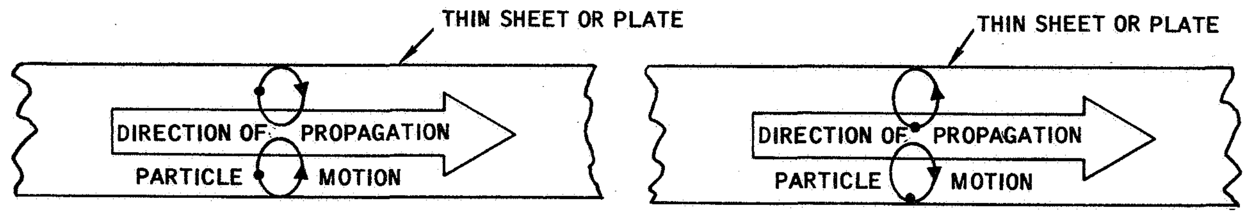
Is the following statement true or false? Surface waves as the name implies travel only on the surface of a material with particle motion following a longitudinal orbit.

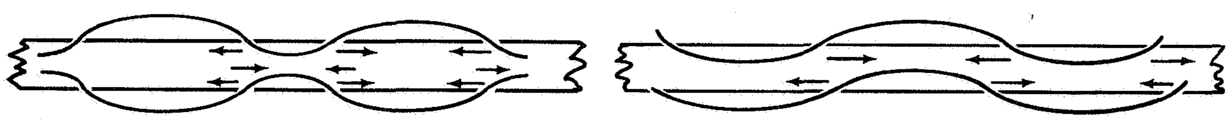
False . . . . Page 3-30

True . . . . Page 3-32

You are correct in choosing the "False" answer. Surface waves travel on the surface of a material with particle motion following an elliptical orbit.

When ultrasonic vibrations are transmitted into a relatively thin sheet or plate, the energy travels in the form of "plate" or "Lamb" waves. Two basic types of plate (Lamb) waves exist, one being symmetrical and the other asymmetrical. And each is capable of having an unlimited number of modes, for example: 1st, 2nd, 3rd, etc.





SYMMETRICAL ASYMMETRICAL

PLATE WAVES

Examples of particle displacement for the two basic types of plate waves are shown above. We find these patterns very complex and somewhat resembling the elliptical orbits of surface waves. Unlike the waves previously described (longitudinal, shear, and surface), plate wave velocity depends not only on the material through which the wave is traveling but also on frequency incidence angle, and plate thickness.

Through which of the following examples can we propagate plate waves?

Block of aluminum . . . . Page 3-33

Sheet of aluminum . . . . Page 3-34

From page 3-28

It is true that when we have total reflection, no energy is being transmitted through the second medium. However, the alternate choice (through the interface) is the better answer to the question. By total reflection, we mean that <u>all</u> of the incident beam's energy is reflected at the surface of the material. No energy enters the second medium.

Turn to page 3-29.

From page 3-29

Your choice "True" is incorrect.

It is true that surface waves travel only on the surface of a material; however, the characteristic particle motion follows an ELLIPTICAL (not longitudinal) orbit. Therefore the statement as given is false.

Turn to page 3-30.

Incorrect. A "block of aluminum" is not a good example for a material that will propagate plate waves. The "sheet of aluminum" is however. Remember that material thickness is an important factor in the propagation of plate waves. Plate waves can exist only in relatively thin materials.

Turn to page 3-35 for a review.

Fine! You chose the correct example (Sheet of aluminum). You remembered that plate waves will propagate only through relatively thin materials.

Turn to page 3-35 for a review.

From page 3-34

1. An ultrasonic sound beam propagates through a medium as wa___s of part___le vib____ions.

7. perpendicular

8. An incident beam's angle of ref____ion at an interface is equal to its angle of in______ce.

14. refraction

15. The angle of refraction is the angle formed between a refracted wave as it passes through an interface and a line drawn (parallel) (perpendicular) ________________ to the interface.

21. solids

22. Surface waves have a velocity slightly less than (longitudinal) (shear) ______________ waves and travel only on the surface of (water) (solids) ______________.

1. waves,
   particle vibrations

2. Various wave modes are used in ultrasonic testing; for example, longitudinal, shear, and surface, etc. The speed at which a wave mode propagates through a medium depends on its characteristic velo____y for the medium.

8. reflection,
   incidence

9. Waves in which particle vibration is in the direction of propagation are called lon________al or com_______on waves.

15. perpendicular

$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2}$$

16. Refraction angles can be calculated using S_______'s L_____.

22. shear,
    solids

23. Waves which propagate only through thin sheets, plate, or thin-walled tubing are called pl_______ or L____b waves.

2. velocity

3. The characteristic velocities for the various wave modes in materials can be found in tables listing the acous______ prop_____ies of materials.

9. longitudinal,
compression

10. Waves in which particle vibration is perpendicular to the direction of propagation are called s______ar or trans________ waves.

16. Snell's Law

17. The angle of incidence which causes 90-degree refraction of a wave mode is called the c________cal angle.

23. plate,
Lamb

24. Particle motion in plate waves is in the form of complex el________cal orbits, the motion being either symmet________ or asy_________cal.

3. acoustic (acoustical) properties

4. The surface between two media is called the inter________.

10. shear, transverse

11. Shear wave velocity is (slightly less than) (approximately half) ________________ the velocity of longitudinal waves.

17. critical

18. When the shear wave mode is refracted 90 degrees (second critical angle), sur______e waves are developed.

24. elliptical, symmetrical, asymmetrical

25. Plate wave velocity depends on wave freq________, inci______ angle, the material and material th______ss.

4. interface

5. Ultrasonic waves approaching an interface are called the inci________ waves or beam.

11. approximately half

12. When a sound beam strikes an interface between two different media at an angle, m____de conv________n occurs.

18. surface

19. Particle motion in surface waves follow an ell__________al orbit.

25. frequency, incidence, thickness

26. When the angle of incidence exceeds the critical angle for shear waves, t__________l re____________n occurs.

5. incident

6. The angle at which an incident beam strikes the interface is the angle of inci________.

12. mode conversion

13. Mode conversion is the transformation of an in________t beam into other modes of vibration.

19. elliptical

20. L______________al waves will propagate through solids, liquids, and gases.

26. total reflection

27. Total reflection means no incident beam en________y is being transmitted through an interface.

6. incidence

7. Normal incidence is when the incident beam is (perpendicular) (at an angle) ____________ to the interface.

Return to page 3-35, frame 9

13. incident

14. The bending of an incident beam as it passes through an interface is called ref________tion.

Return to page 3-35, frame 16

20. Longitudinal

21. Shear waves propagate only through (solids) (liquids) (gases) ____________.

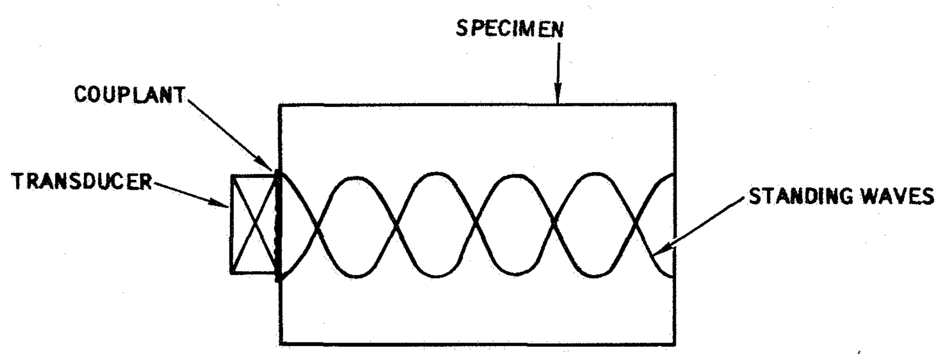
Return to page 3-35, frame 23

27. energy

28. This completes the review of Chapter 3. Turn to page 3-42.

Now you are ready to start back through the book and read those upside-down pages.

Now that you are familiar with ultrasonic waves and how they're generated, let's take up the phenomenon commonly referred to as "resonance." Resonance can be defined as the characteristic of a vibrating body to - under certain conditions - resonate or vibrate in sympathy with a vibration source. The vibration source in this case is the transducer. And the vibrations are continuous longitudinal waves.



RESONANCE

As shown in the illustration above, a resonant condition will exist anytime a continuous longitudinal wave is introduced into a specimen and reflected "in phase" with the incoming wave. Standing waves are set up and the specimen vibrates with considerable increase in amplitude.

To excite resonance within a specimen, we use...

pulsed longitudinal waves . . . . .Page 4-2

continuous longitudinal sound waves . . . . .Page 4-3

No, you're not right. We use <u>continuous</u> longitudinal waves to excite resonance within a specimen, not pulsed longitudinal waves (your answer).

Recall from Chapter 1 that "pulsed sound" refers to short "bursts" of vibrations, before or after which there are no vibrations for a given time interval. This type of sound beam will not support resonance. "Continuous sound" - as the name implies - refers to vibrations that are repeated continuously <u>without</u> any pauses in time.

Remember - that to set up a <u>resonant condition</u> within a specimen - the sound beam must be <u>continuous</u>. The wave mode must be <u>longitudinal</u>.

Turn to page 4-3.

Right. Continuous longitudinal sound waves are used to excite resonance within a test specimen.

To further define resonance, we find that the transmitted and reflected waves in a specimen will be "in phase" only when the specimen's thickness is equal to a half-wavelength or whole number multiples thereof. In other words, resonance will occur only when the thickness of a specimen is equal to a half-wavelength or exact multiples of a half-wavelength.

You learned in the preceding chapters that if we change a wave's frequency, its wavelength will also change. By applying this relationship of frequency and wavelength, we can set up a resonant condition in any material thickness by simply varying the frequency of the transmitted wave till a half-wavelength or one of its exact multiples equals the material thickness.

Select the best completion for the following statement.

Resonance will occur anytime a continuous longitudinal wave is transmitted into a specimen and . . .

the wavelength is varied till standing waves are set up . . . . .Page 4-4

the frequency is varied till standing waves are set up . . . . .Page 4-5

Your choice is not the best selection. It is true that the wavelength is varied; but, don't we change the wavelength by varying the frequency? Yes.

Recall the relationship between wavelength, frequency, and velocity.

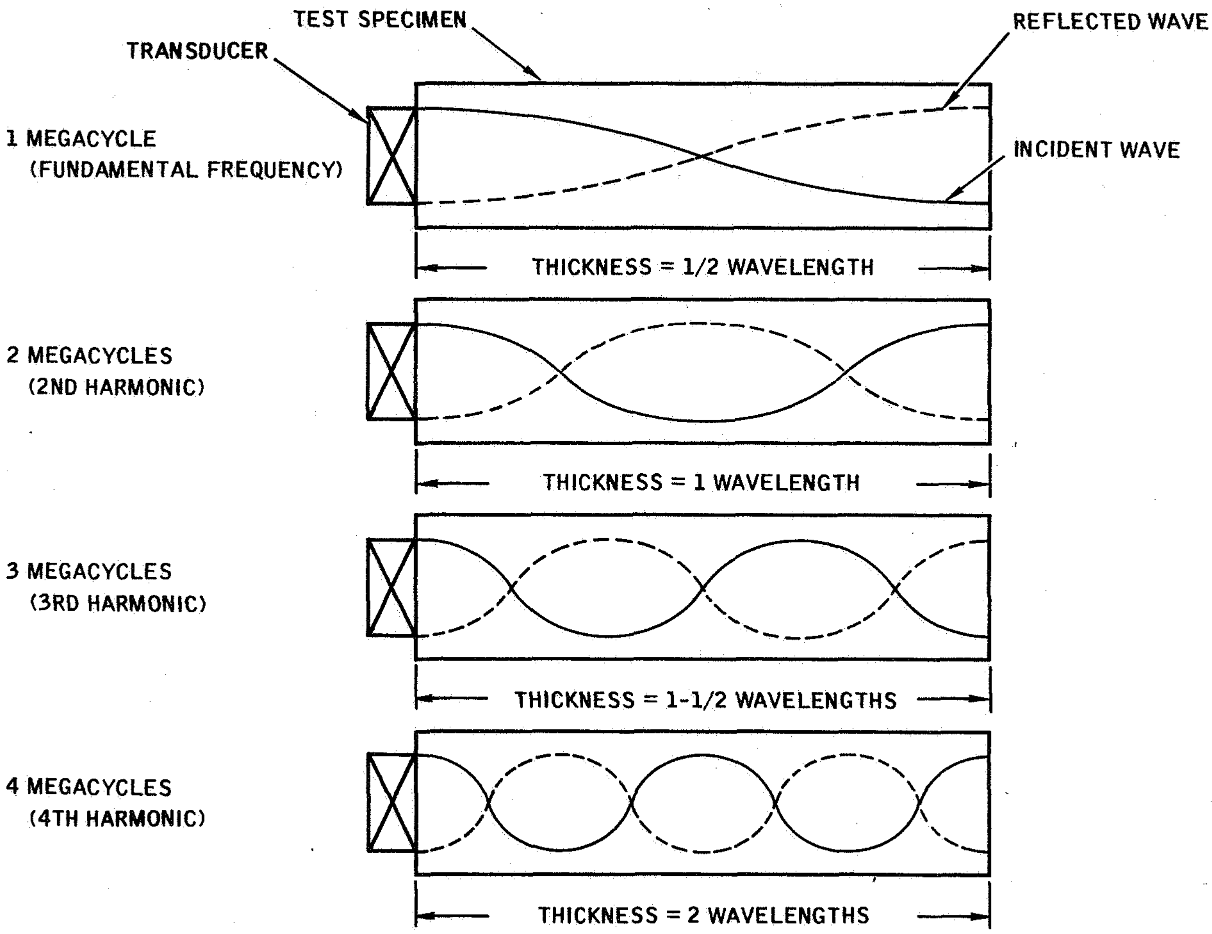
$$\text{WAVELENGTH} = \frac{\text{VELOCITY}}{\text{FREQUENCY}} \qquad \text{or} \qquad \lambda = \frac{v}{f}$$

You learned that velocity is a fixed value and remains constant for a given material. You also learned that if we increase the frequency, wavelength will decrease. If we decrease frequency, the wavelength will increase. Therefore, in order to set up a resonant condition, don't we vary the frequency? Yes.

Turn to page 4-5.

Correct. Resonance will occur anytime a continuous longitudinal wave is transmitted into a specimen and the frequency is varied till standing waves are set up.

Shown below are several resonance wave patterns.



The first pattern illustrates the "fundamental resonant frequency" and the others are whole number multiples thereof called "harmonics."

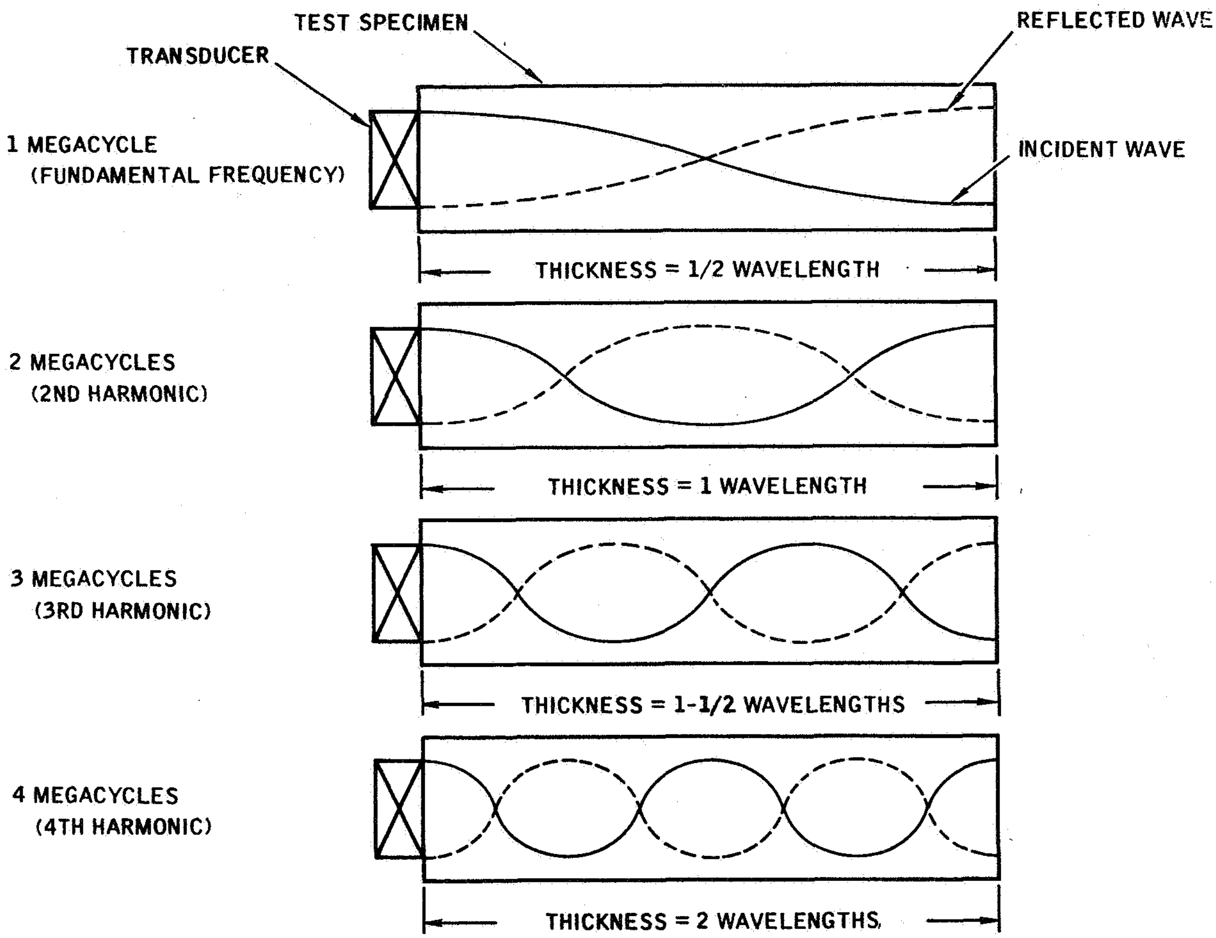
From the examples, would you say that for a given specimen thickness, resonance will occur at several different frequencies?

No . . . . Page 4-6

Yes . . . . Page 4-7

Your choice "no" is incorrect. For a given specimen thickness, resonance <u>does occur</u> at several different frequencies.

Recall the resonant frequency wave patterns.



The first example shows a 1 megacycle sound wave applied to a test specimen. The specimen thickness is equal to 1/2 wavelength. The second, third, and fourth examples show 2, 3, and 4 megacycle sound waves applied to the specimen. The "harmonics" are exact multiples of the "fundamental resonant frequency," e.g., 1 wavelength, 1-1/2 wavelength, etc. Don't the examples indicate that resonance occurs at 2, 3, and 4 megacycles as well as at 1 megacycle? Yes. Aren't each of the examples of the same thickness? Of course. From the examples, we can see that resonance occurs at several different frequencies for a given material thickness.

Turn to page 4-7.

Right! Resonance occurs at several different frequencies for a given specimen thickness.

The fundamental resonant frequency is the minimum frequency at which a given material thickness will resonate. It is also the frequency at which resonance amplitude will be at its highest. And since wavelength and frequency are related to material thickness, the fundamental resonant frequency can be determined from the formula

$$F = \frac{V}{2T}$$

where F = fundamental resonant frequency

V = velocity of longitudinal waves within the given material

T = material thickness

For example, let's say we have a 1/2-inch thick piece of steel plate and we want to know its fundamental resonant frequency. First we must change inches to centimeters as most tables list the acoustic velocities of materials in centimeters. By multiplying 0.5 inch (the steel thickness) x 2.54 (the conversion factor for changing inches to centimeters), we get 1.27 which is the thickness of the steel in centimeters.

Using the formula $F = \frac{V}{2T}$ and substituting the following values for V and T:

V = 0.585 cms/microsecond (velocity of longitudinal waves in steel obtained from table of acoustic properties)

T = 1/2 inch = 1.27 centimeters (calculated above)

$$F = \frac{0.585}{2 \times 1.27}$$

$$F = 0.230$$

The fundamental resonant frequency is 0.230 megacycles. This is the minimum frequency at which the 1/2-inch steel will resonate.

Turn to page 4-8.

From page 4-7

As another example, let's find the fundamental resonant frequency for a piece of 1/4-inch aluminum plate.

First we convert the 1/4-inch thickness to centimeters by multiplying 0.25 x 2.54. The equivalent thickness in centimeters is 0.635 centimeters.

Using the formula $F = \frac{V}{2T}$ and substituting the following values V and T:

V = 0.625 cms/microsecond (velocity of longitudinal waves in 17ST aluminum)

T = 0.635 centimeters

$$F = \frac{0.625}{2 \times 0.635}$$

The fundamental resonant frequency for the 1/4-inch aluminum plate is 0.492 megacycles.

Select the best answer to the following statement.

The fundamental (minimum) resonant frequency of a specimen is...

proportional to the velocity of longitudinal waves in the material and inversely proportional to twice the thickness . . . . Page 4-9

proportional to the velocity of shear waves in the material and inversely proportional to the thickness . . . . Page 4-10

From page 4-8

Correct! The fundamental (minimum) resonant frequency of a specimen is proportional to the velocity of longitudinal waves in the material and inversely proportional to twice the thickness.

If we use the formula $F = \frac{V}{2T}$ and calculate the fundamental resonant frequency for a 1/2-inch thick aluminum plate, we will obtain a fundamental resonant frequency of 0.246 megacycles. Recall that the fundamental resonant frequency for the 1/4-inch aluminum plate was 0.492 megacycles. From this, we can see the fundamental resonant frequency decreases with increasing thickness for a given material.

Can we say that for a given material, frequency and thickness are inversely proportional?

Yes . . . . Page 4-11
No . . . . Page 4-13

Incorrect. The fundamental (minimum) resonant frequency of a specimen is proportional to the velocity of longitudinal waves in the material and inversely proportional to twice the thickness. Again, this relationship is expressed by the formula:

$$F = \frac{V}{2T}$$

Frequency (F) is equal to velocity(V) divided by twice the thickness (T).

Also, remember that continuous longitudinal or compression waves (not shear waves) are used to excite resonance.

Turn to page 4-9.

From page 4-9

Right again! We <u>can</u> say that for a given material, frequency and thickness are inversely proportional. An increase in thickness produces a decrease in the fundamental resonant frequency and vice versa.

You probably suspect by now that not all resonances are of a fundamental resonant frequency. You're right. A resonant condition also can be set up using a <u>harmonic</u>. Again, harmonics are exact multiples of a given fundamental resonant frequency.

Recall the example of the 1/4-inch aluminum plate. We found its fundamental resonant frequency to be 0.492 megacycles. Its harmonics are exact multiples. For example, the 2nd harmonic would be 0.984 megacycles, and the 3rd harmonic ... 1.476 megacycles, etc.

Let's say we have a piece of 1/2-inch steel plate and its fundamental resonant frequency is 0.230 megacycles. Its 3rd harmonic is...

0.460 megacycles . . . . Page 4-12

0.690 megacycles . . . . Page 4-14

Your choice (0.460 megacycles) is not the 3rd harmonic for the given example. The 3rd harmonic is 0.690 megacycles.

Recall that harmonics are exact multiples of the fundamental resonant frequency. If we want to know the 2nd harmonic, we simply multiply the fundamental resonant frequency by 2. If we want to know the 6th harmonic, we multiply by 6, etc. The 3rd harmonic for 0.230 megacycles would be 0.690 megacycles ... right? Right.

Turn to page 4-14.

Your choice "no" is incorrect. For a given material, frequency and thickness <u>are inversely proportional</u>.

Recall that the 1/4-inch aluminum plate had a fundamental resonant frequency of 0.492 megacycles and the 1/2-inch aluminum was 0.246 megacycles. Isn't this a decrease in frequency while the material thickness increased? Yes. The fundamental resonant frequency for a 1/8-inch thick aluminum plate is 0.981 megacycles. Isn't this an increase in frequency for a decrease in thickness? Yes. Therefore, frequency and thickness can be said to be inversely proportional.

Turn to page 4-11.

From page 4-11

You selected the correct answer. The 3rd harmonic for the given fundamental resonant frequency is 0.690 megacycles. The alternate choice was the 2nd harmonic (0.460 megacycles).

It might be well to know at this point that resonance amplitude decreases with increasing harmonics. The 2nd harmonic will have less amplitude than the fundamental resonant frequency, and the 3rd harmonic will have less amplitude than the 2nd, and so on as the frequency increases. The higher the harmonic ... the lower the amplitude. You should also know that the frequency interval between any two adjacent harmonics equals the fundamental resonant frequency.

Let's use the example of the 1/2-inch steel plate again. The fundamental resonant frequency is 0.230 megacycles. Its 2nd harmonic is at 0.460 megacycles and its 3rd, 0.690 megacycles. By subtracting the 2nd harmonic from the 3rd, we can determine the fundamental resonant frequency

	0.690	3rd Harmonic
-	0.460	2nd Harmonic
	0.230	Fundamental Resonant Frequency

The fundamental resonant frequency is the ...

difference between two adjacent harmonics . . . . Page 4-15

difference between any two harmonics . . . . Page 4-16

From page 4-14

You're right. The fundamental resonant frequency is the difference between two <u>adjacent</u> harmonics.

In summation, you have learned that in ultrasonic resonance ...

- Continuous longitudinal waves are transmitted into a specimen
- Resonance occurs when material thickness is equal to a half-wavelength or exact multiples thereof
- Wavelength is changed by varying the frequency
- Resonance occurs at more than one frequency for a given material thickness
- The fundamental resonant frequency is the lowest frequency at which a specimen will resonate
- Harmonics are exact multiples of the fundamental (minimum) resonant frequency
- The difference between two adjacent harmonics equals the fundamental resonant frequency
- Resonance amplitude decreases with increasing harmonics

Turn to page 4-17 for a review.

Your choice "The fundamental resonant frequency is the difference between any two harmonics" is wrong. It is the difference between <u>two adjacent harmonics</u>. By this, we mean the difference between the 2nd and 3rd harmonics, 3rd and 4th, or 7th and 8th, etc.

Turn to page 4-15.

From page 4-15

1. In ultrasonic resonance, con__________ l____________ waves are transmitted into a specimen.

3. frequency

4. The fun_____________ r_____________ frequency is the minimum frequency at which a given material thickness will resonate.

6. harmonics

7. Frequency and material thickness are inversely proportional. An increase in thickness causes (an increase) (a decrease) ____________ in the fundamental resonant frequency.

9. harmonic frequencies, fundamental resonant

10. Turn to page 5-1.

1. continuous
longitudinal

2. Resonance occurs when the material thickness is equal to a (half) (full) ____________ wavelength, or exact multiples thereof.

4. fundamental resonant

5. The formula $F = \frac{V}{2T}$ is used to determine the f______________ r______________ f______________.

7. a decrease

8. Resonance amplitude (increases) (decreases) ______________ with increasing harmonics.

2. half

3. Wavelength is changed by varying the f______________.

Return to page 4-17, frame 4.

5. fundamental resonant frequency

6. Exact or whole number multiples of a fundamental resonant frequency are called h ______________.

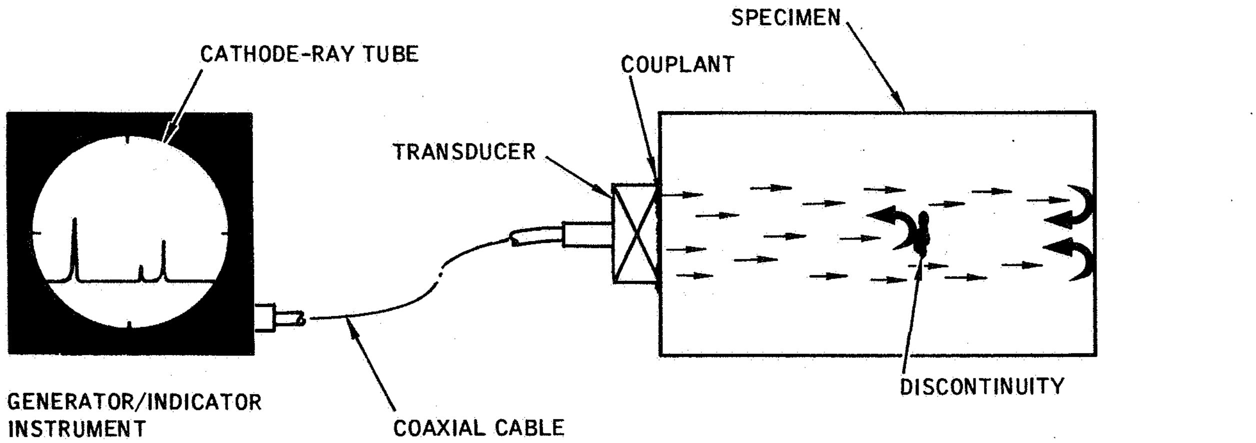
Return to page 4-17, frame 7.

8. decreases

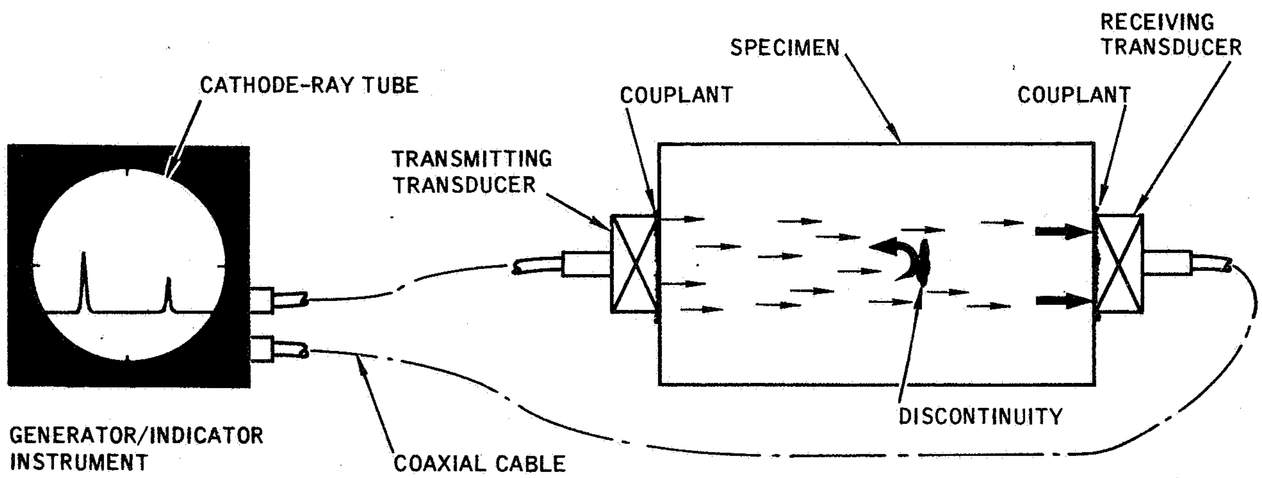
9. The frequency difference between two adjacent h____________ f _________ies equals the f ____________ r ______________ frequency.

Return to page 4-17, frame 10.

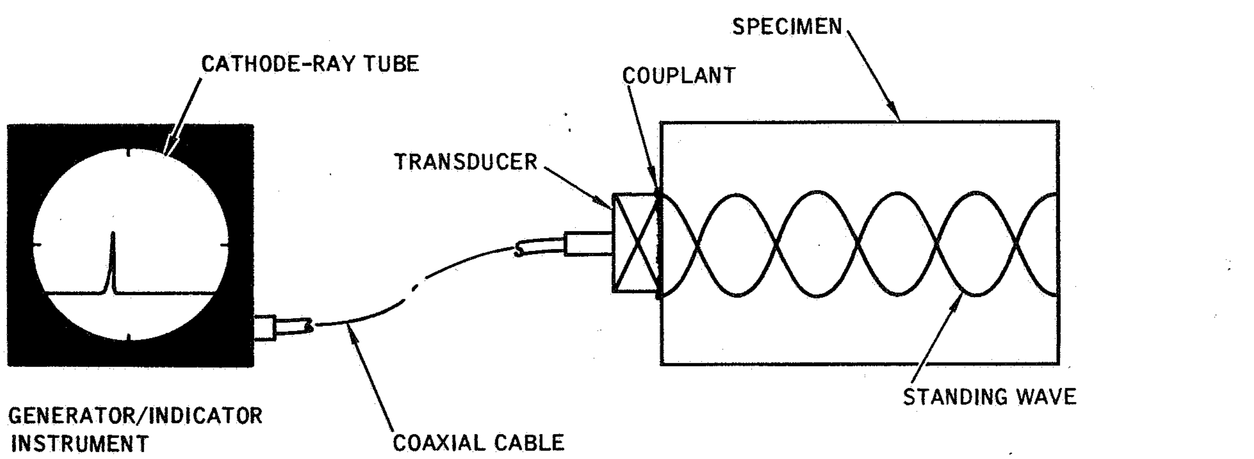
There are three basic ultrasonic test systems used in nondestructive testing. These systems are "pulse-echo," "through transmission," and "resonance."



PULSE-ECHO SYSTEM



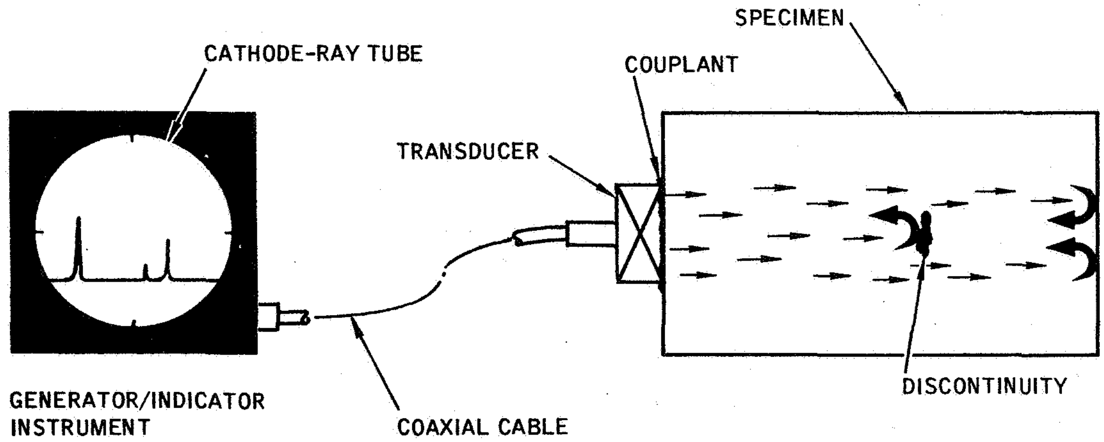
THROUGH TRANSMISSION SYSTEM



RESONANCE SYSTEM

Turn to page 5-2.

The most widely used system is the PULSE-ECHO system.



PULSE-ECHO SYSTEM

In this system, short, evenly timed pulses of ultrasonic waves are transmitted into the material being tested. These pulses reflect from discontinuities in their path, or from any boundary of the material on which they strike. The received reflections or echos are then usually displayed on a cathode-ray tube (CRT). The CRT furnishes specific data as to the relative size of a discontinuity and its depth in the material. A single transducer is used as both the transmitter and receiver, although sometimes two transducers are used, one acting as the transmitter and the other as the receiver.

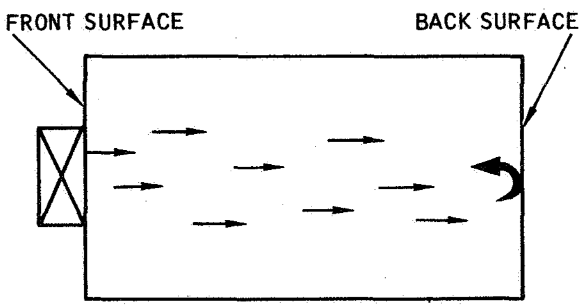
Which of the following statements is true?

The pulse-echo system relies on the overall transmitted energy, or lack of energy, reaching the receiving transducer for discontinuity indications . . . . Page 5-3

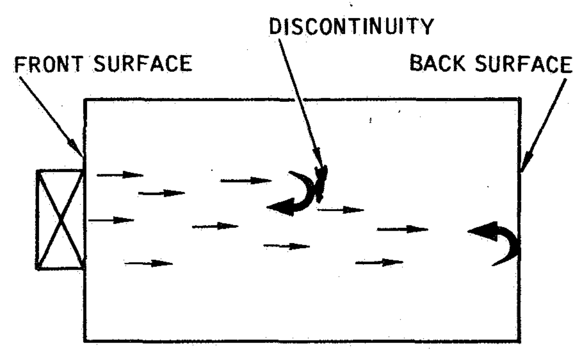
The pulse-echo system relies on reflected energy reaching the receiving transducer for discontinuity indications . . . . Page 5-4

You chose the incorrect statement. The pulse-echo system relies on REFLECTED ENERGY (not transmitted energy) reaching the receiving transducer for discontinuity indications.

From the discussions on wave propagation and reflection, we learned that waves are both reflected and transmitted at an interface. The percentage of reflection and transmission is dependent on the acoustical impedance ratio of the materials making up the interface. Discontinuities act very much like interfaces having extremely high impedance ratios. Examples of wave propagation through both a sound material and a defective material are shown below.



SOUND MATERIAL



DEFECTIVE MATERIAL

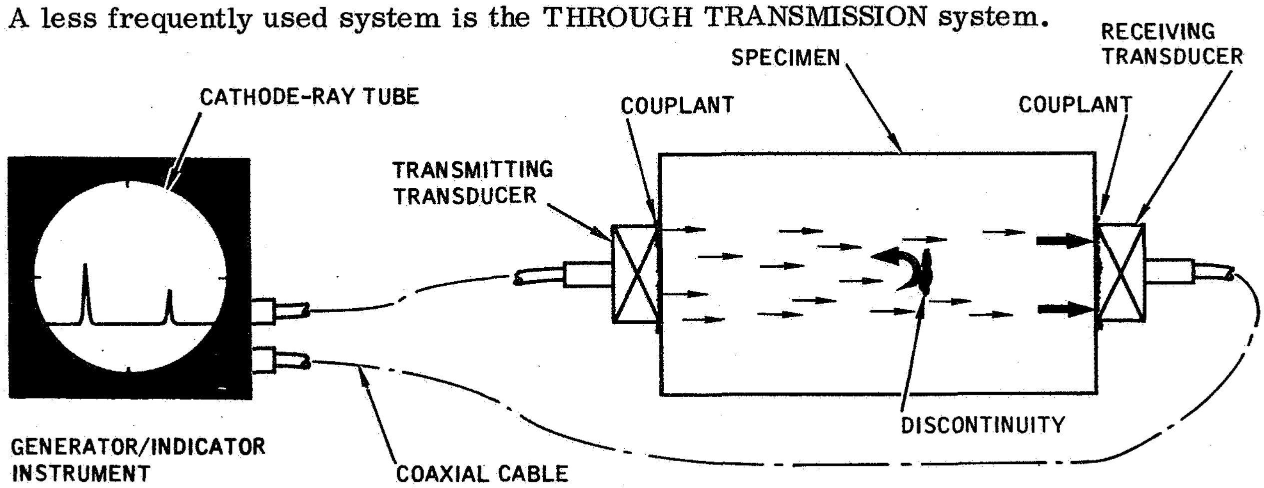
In the sound material, a pulse of energy travels through the material, reflects off the back surface, and returns to its source as one pulse. In the defective material, a portion of the original pulse is reflected at the discontinuity and returns to the transducer before the original pulse. The pulse-echo system uses this difference in received reflections to locate discontinuities in materials.

Turn to page 5-4.

From page 5-2

Right! We can say the pulse-echo system relies on reflected energy reaching the receiving transducer for discontinuity indications. The receiving transducer in most cases is also the transmitting transducer.

A less frequently used system is the THROUGH TRANSMISSION system.



THROUGH TRANSMISSION SYSTEM

The through transmission system requires the use of two transducers. One transducer is used solely as a transmitter while the other is used as the receiver. As in pulse-echo testing, short pulses of ultrasonic waves are transmitted into the material... although continuous waves are sometimes used. And, unlike the pulse-echo system, echos returning to the transmitting transducer are not used. The receiving transducer is aligned with the transmitting transducer to pick up the sound waves which pass directly (or indirectly) through the material. The soundness or quality of the material being tested is in terms of energy lost by a sound beam as it travels through the material.

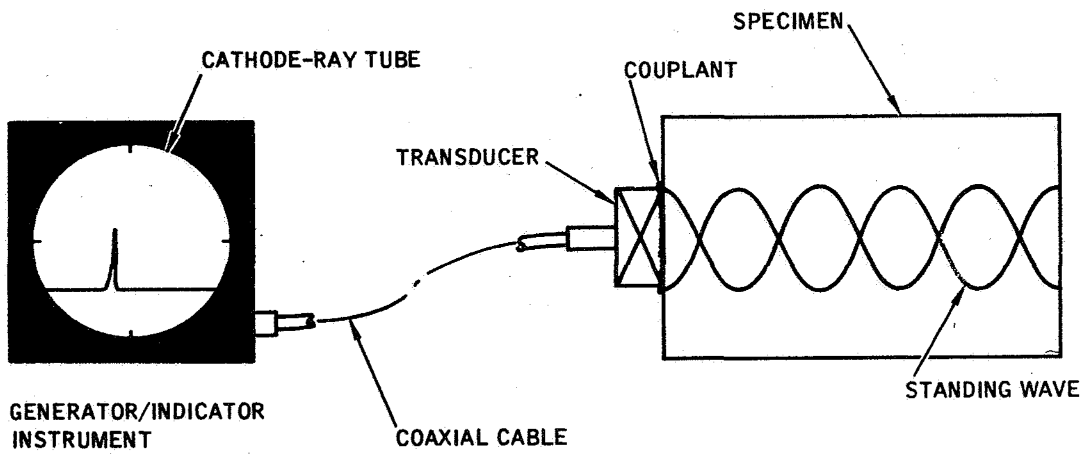
Select the best completion for the following statement. The through transmission system reveals discontinuities in a material by indicating the...

variations in received energy amplitude . . . . Page 5-5

difference between transmitted and reflected energy . . . . Page 5-8

Correct! The through transmission system reveals discontinuities in a material by indicating variations in received energy amplitude. A marked reduction in the received energy's amplitude indicates a discontinuity.

The RESONANCE system makes use of the resonance phenomenon to measure material thicknesses and to determine the quality of bonded materials. The system also is used - but to a lesser degree - to detect gross discontinuities.



RESONANCE SYSTEM

The resonance system transmits ultrasonic waves into a material similar to the pulse-echo system except the waves are always continuous longitudinal waves. Wave frequency is varied till standing waves are set up within the specimen, causing the specimen to resonate or vibrate at a greater amplitude. Resonance is then sensed by the generator/indicator instrument and presented as a "pip" on a CRT screen, a meter deflection, or an audible sound change in an earphone, etc. A change in resonant frequency which cannot be accounted for as a change in material thickness is usually an indication of a discontinuity.

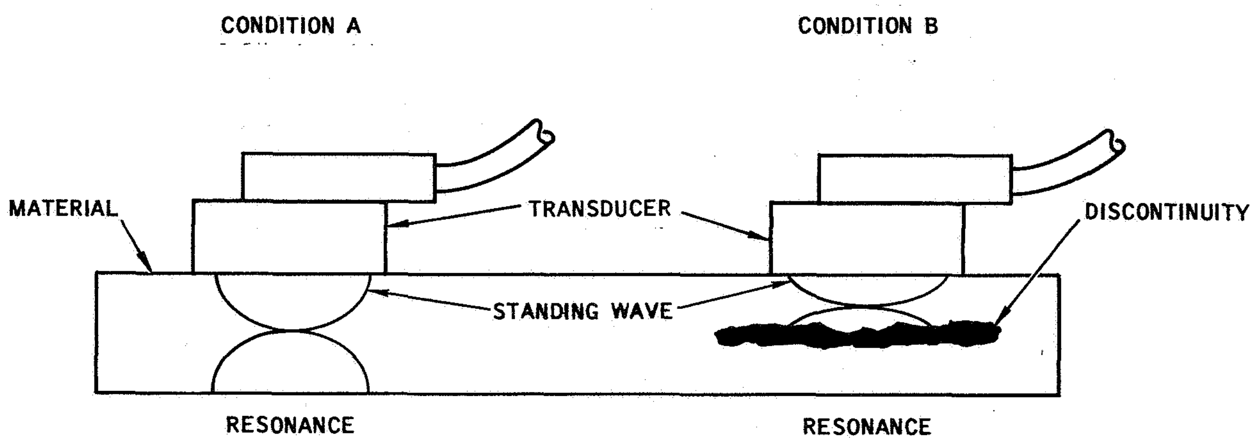
Can we say the resonance system relies on variations in the resonant frequency for a given thickness of material to locate discontinuities?

No . . . . Page 5-6

Yes . . . . Page 5-7

Your choice "no" is not correct. The resonance system DOES rely on variations in resonant frequency for a given thickness of material to locate discontinuities.

For example, let's couple the transducer of a resonant system to a piece of material. We then adjust the frequency till the material resonates and a standing wave (a half-wavelength or exact multiples thereof) is set up as shown in condition A, below.



Now if we move the transducer over a discontinuity, the material will stop resonating at the selected frequency and we lose the standing wave. The wavelength is now too long. The discontinuity acts like a change in material thickness. We must readjust the frequency setting and therefore the wavelength to obtain a new standing wave as shown in condition B.

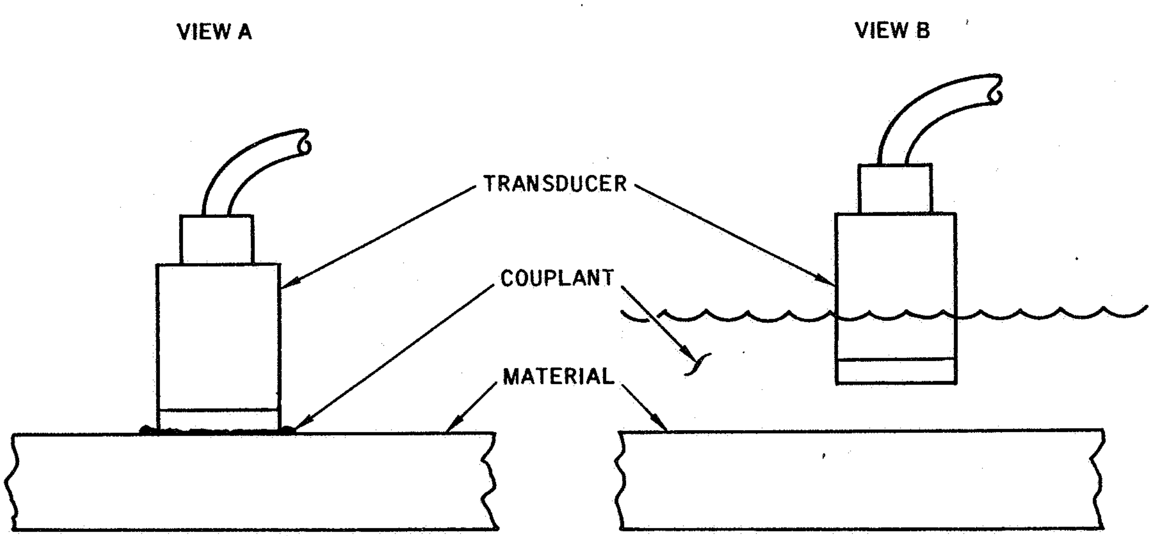
Doesn't the resonance system rely on variations in the resonant frequency for a given material thickness to find discontinuities? Yes.

Turn to page 5-7.

Fine! We can say the resonance system relies on variations in resonant frequency for a given thickness of material to locate discontinuities.

Now let's take up the terms which identify the test methods used in ultrasonic testing. The testing method in which the transducer is placed in direct contact with the surface of the material being tested is called "contact testing". In contact testing, the transducer is coupled to the material through a thin layer of couplant, usually a liquid, semi-liquid or paste. In Chapter 2 we learned the couplant ensures maximum transfer of energy between the transducer and material. Contact testing is most frequently used in the field and shop locations. The equipment is usually "portable" and can be brought to the job.

Which of the following views illustrates contact testing best?



View A . . . . Page 5-9

View B . . . . Page 5-10

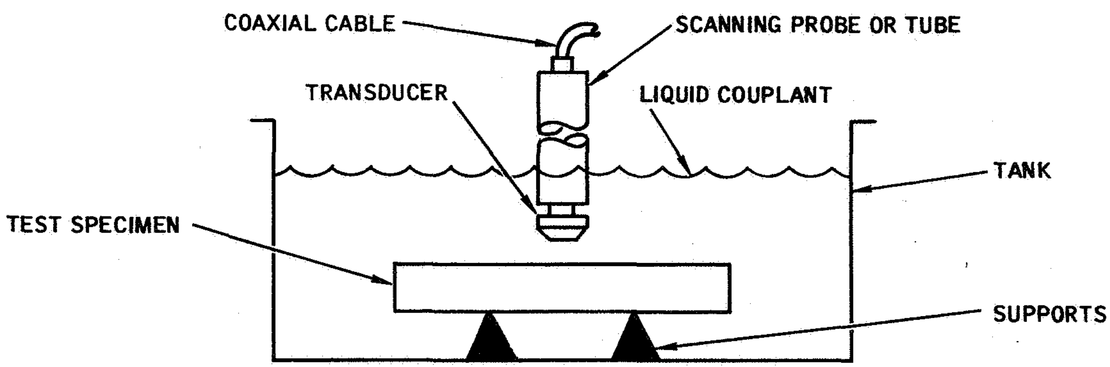
You're incorrect. The through transmission system does reveal discontinuities in a material by indicating VARIATIONS IN RECEIVED ENERGY AMPLITUDE.

Remember that with through transmission, reflected energy is not used. We determine a material's soundness or quality by the amount of energy (or loss of energy) received at the receiving transducer. Therefore, variations in received energy amplitude would indicate a discontinuity.

Turn to page 5-5.

Good for you! View A does illustrate contact testing best. The transducer is shown in direct contact with the material being tested.

"Immersion testing" is another method used in ultrasonic testing. Both the material (test specimen) and the transducer are immersed in a liquid couplant and ultrasonic vibrations are applied to the specimen through the liquid. The transducer does not touch the material being tested.



IMMERSION TESTING

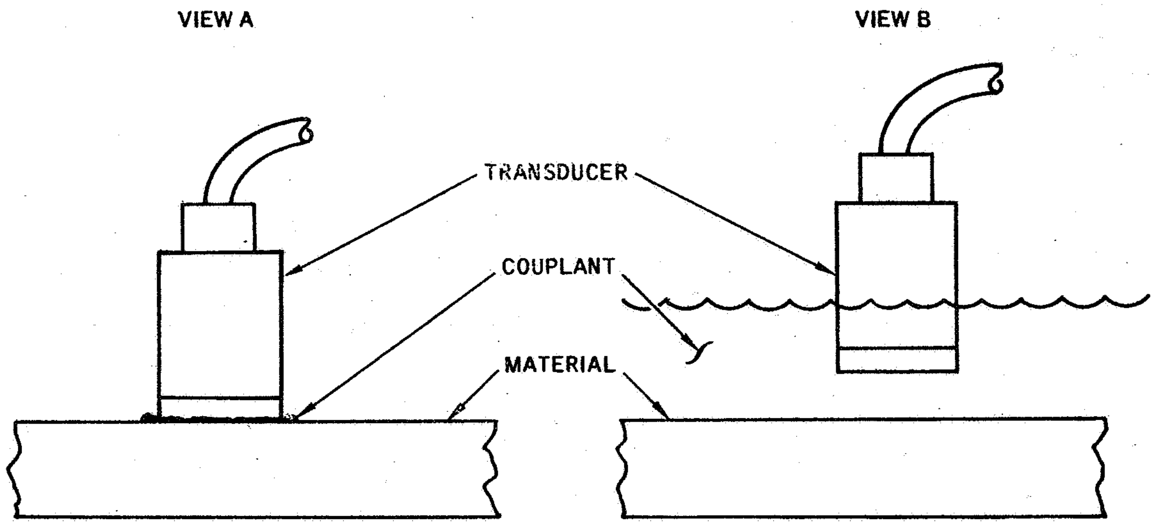
The couplant is usually water with a wetting agent added. Special supports are required for the test specimen and manipulators are used to position the scanning probe or tube containing the transducer.

Select the better completion for the following statement. When we use the immersion testing method, we immerse the...

test specimen in a liquid couplant . . . . Page 5-11

test specimen and the transducer in a liquid couplant . . . . Page 5-12

Incorrect. View B shows the transducer separated from the surface of the material.



Remember that in contact testing, the transducer is placed <u>directly</u> on the material with a thin layer of couplant between the transducer and the material. Doesn't view A best illustrate this principle? Yes.

Turn to page 5-9.

From page 5-9

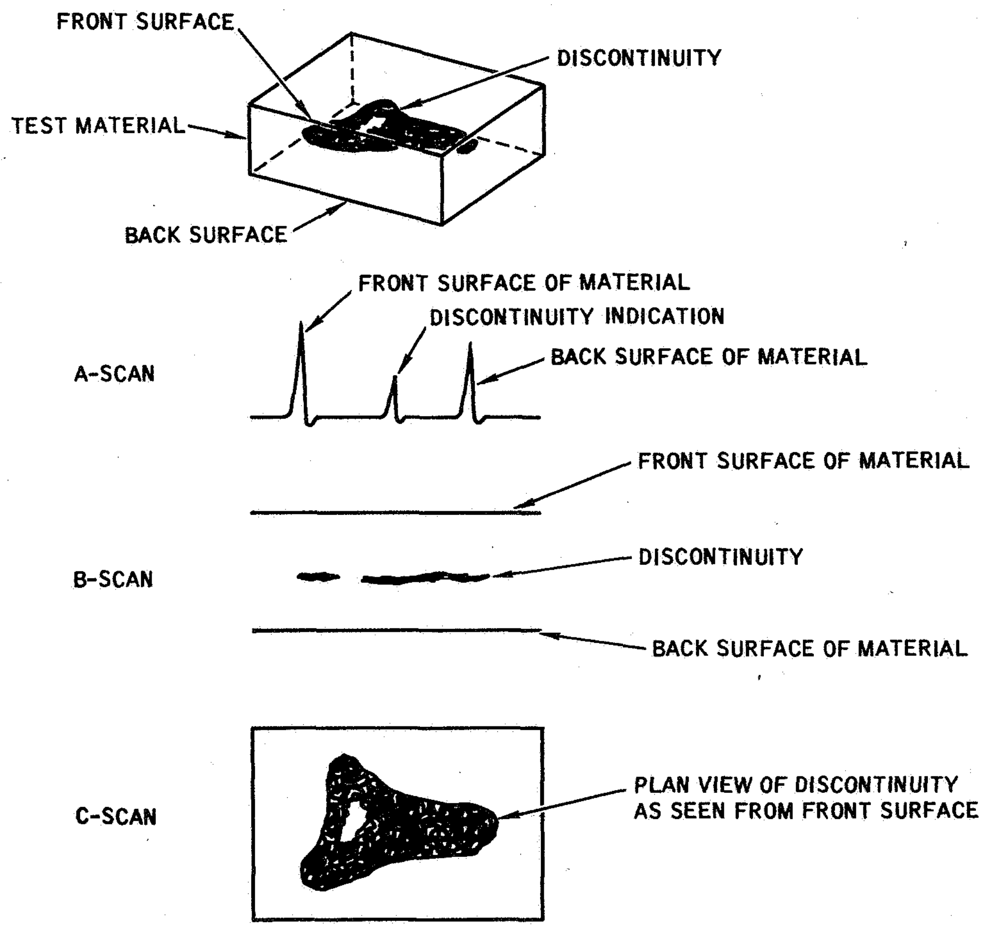
When we use the immersion testing method, we do immerse the test specimen in the liquid couplant but don't we also immerse the transducer? Yes. The liquid couplant acts as the transmission medium for the ultrasonic vibrations or waves between the transducer and the test specimen; therefore, the transducer must be immersed also.

Turn to page 5-12.

From page 5-9

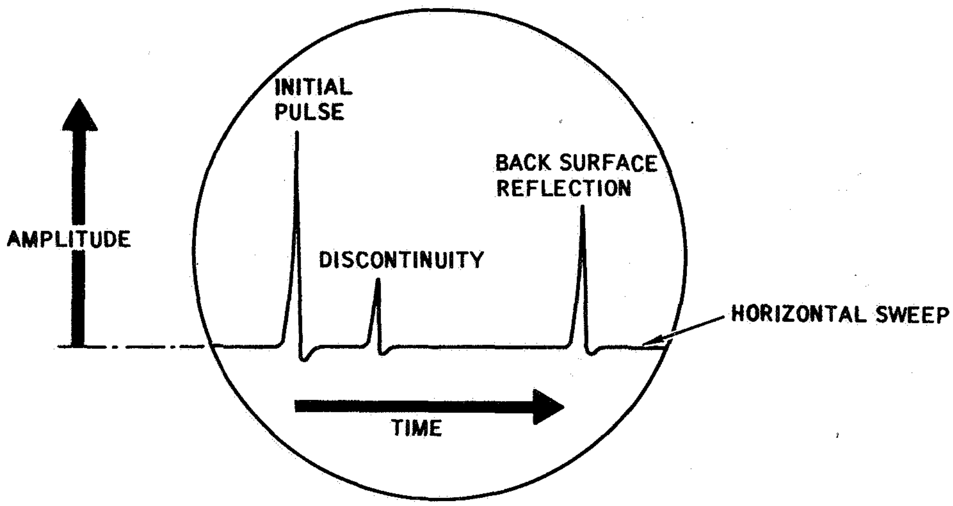
Right! In immersion testing we immerse both the test specimen and the transducer in a liquid couplant.

There are three types of visual displays which will show the soundness or quality of a material being tested. These are the "A-scan", "B-scan", and the "C-scan" presentations.



Turn to page 5-13.

The A-scan presentation is a "time versus amplitude" display which reveals the existence of discontinuities using "pips" on a cathode-ray tube (CRT). From the pip location on the CRT and its amplitude, we can find the relative depth of a discontinuity in the material and estimate its size.



A-SCAN PRESENTATION

Can we identify the A-scan presentation as an indication obtained from the horizontal sweep of a cathode-ray tube?

No . . . . Page 5-14

Yes . . . . Page 5-15

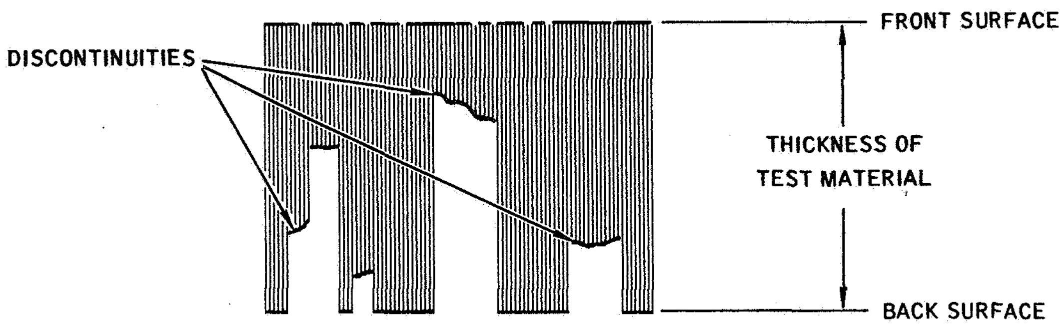
"No" is not the correct answer. The A-scan presentation CAN be identified as an indication obtained from the horizontal sweep of a cathode-ray tube. By horizontal sweep, we mean the horizontal line of light across the face of the CRT.

Turn to page 5-15.

From page 5-13

Excellent. The A-scan presentation is an indication obtained from the horizontal sweep of a cathode-ray tube. How we interpret the "pips" on the horizontal sweep will be discussed later in this chapter.

The B-scan presentation applies mostly to the medical applications of ultrasonics and is generally not used in nondestructive testing. However, when used it gives a cross-sectional view of the material being tested.



B-SCAN PRESENTATION

The B-scan presentation shows the reflections of the front and back surfaces of the test material and the discontinuity. The display is usually shown on a CRT screen or a paper recording from a recorder.

Will the B-scan presentation show the length and depth of a discontinuity in the test material?

No . . . . Page 5-16

Yes . . . . Page 5-17

Wrong. The B-scan presentation will show the length and depth of a discontinuity in the test material.

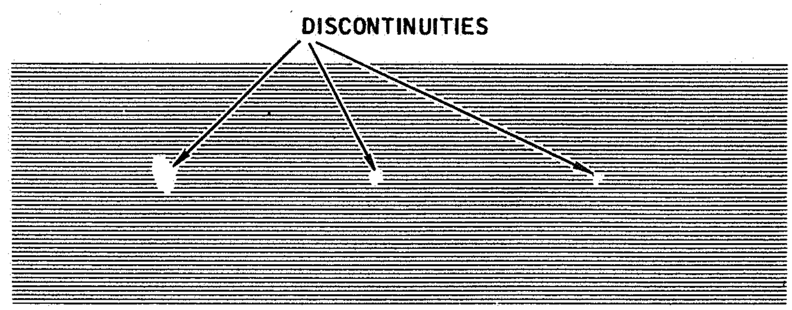
Didn't we learn the B-scan presentation is a cross-sectional view of a material? Yes. It therefore will show the length and depth of a discontinuity.

Turn to page 5-17.

From page 5-15

Right! We can use the B-scan presentation to show the length and depth of a discontinuity in the test material.

The C-scan presentation is a plan view indication similar to an X-ray picture. It projects the internal details of a material into a plane. If a discontinuity exists, a contour of the discontinuity is obtained.



C-SCAN PRESENTATION

In a C-scan display, the front and back surface reflections are not used, only the reflection from the discontinuity.

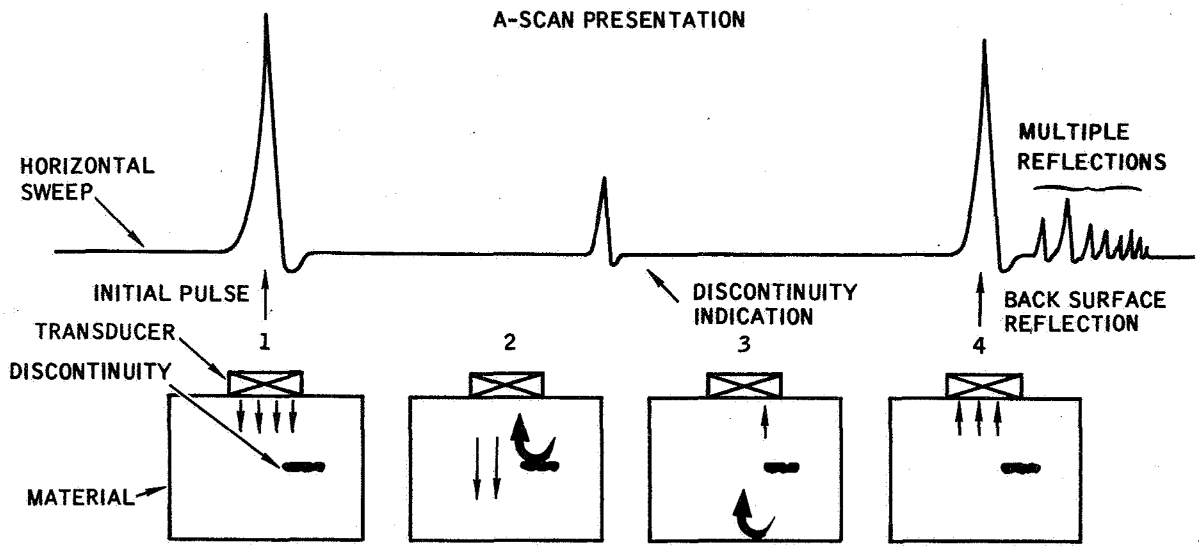
Select the best completion for the following statement. The C-scan presentation shows the...

shape of a discontinuity as viewed from the front surface of the test material . . . . Page 5-18

depth of a discontinuity as viewed from the front surface of the test material . . . . Page 5-20

Very good! The C-scan presentation shows the shape of a discontinuity as viewed from the front surface of the test material. This display is usually a paper recording, however, a CRT is sometimes used.

Now let's learn how to interpret a simple A-scan presentation. Shown below is what happens as an ultrasonic wave passes through a material containing a discontinuity and the corresponding CRT presentation.



The first indication (initial pulse) appears at the left of the CRT screen and the back surface reflection is spaced to the right. The discontinuity is shown somewhere between the initial pulse and the back surface reflection. In actual practice, some of the wave energy continues to reflect back and forth in the material till it is absorbed and dissipated as heat. These reflection multiples usually appear on the CRT to the right of the first back surface reflection.

Is the following statement true or false? The A-scan presentation is read right to left with first the initial pulse followed by the discontinuity reflection (if present), the back surface reflection and their multiples.

True . . . . Page 5-19

False . . . . Page 5-21

Incorrect. The statement is "False". Didn't we learn the initial pulse appears at the left of the CRT screen with the discontinuity (if present), back surface reflection and multiples spaced to the right in that order? Yes. Therefore, isn't the A-scan presentation read left to right? Yes.

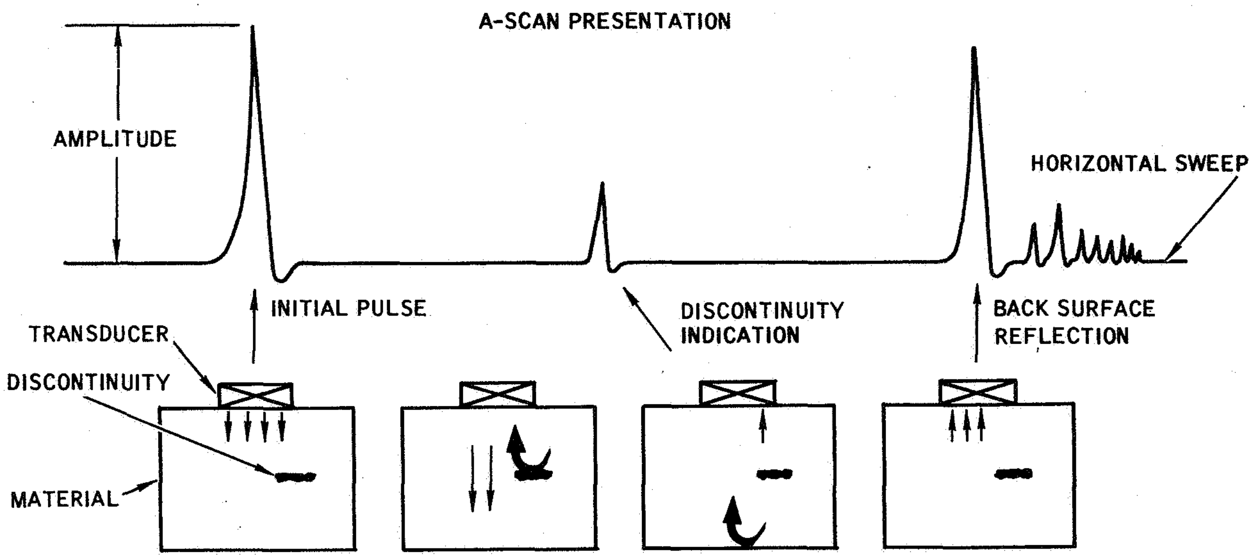
Return to page 5-18, review the material and try the question again.

Wrong. The C-scan presentation does not use the front or back surface reflections, therefore it will not indicate the depth of a discontinuity. The C-scan presentation displays a plane view of the material being tested as viewed from the front surface. Will not this plane view show the shape of a discontinuity? Yes.

Turn to page 5-18.

Right. The statement is "false". The A-scan presentation is read <u>left to right</u> with the initial pulse appearing on the left side of the screen followed by the discontinuity reflection (if present), the back surface reflection and their multiples.

The height of the pips or vertical deflections of the sweep represents the amplitude of the wave reflections (echoes) coming from the material being tested.



By comparing the height of the discontinuity pip with that from a known size discontinuity in a like material, we can determine the size of the discontinuity in the material being tested.

Choose the correct completion for the following statement. Pip height or amplitude is used to determine...

discontinuity shape . . . . Page 5-22

discontinuity size . . . . Page 5-23

From page 5-21

You chose the incorrect answer. In the A-scan presentation, pip height or amplitude is used to determine the SIZE of a discontinuity, not its shape. The shape of a discontinuity is determined by using the C-scan presentation.

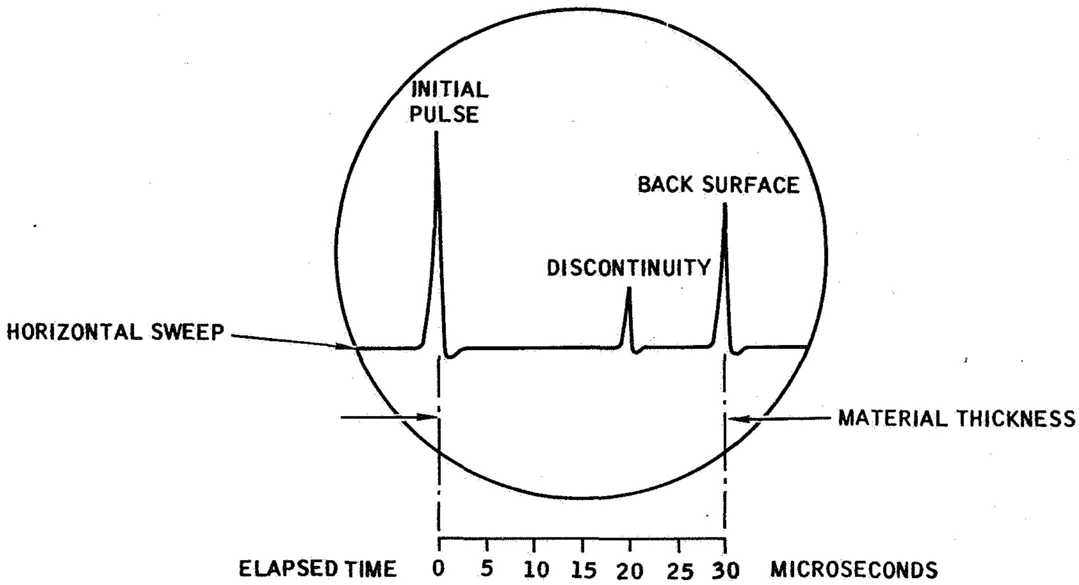
Turn to page 5-23.

[redacted]

From page 5-21

Excellent! The height or amplitude of a pip is used when determining the size of a discontinuity.

We learned in preceding discussions on the A-scan presentation the initial pulse appears at the left of the CRT screen with the discontinuity and back surface reflections spaced toward the right along the horizontal sweep line.



A-SCAN PRESENTATION

The distance from the initial pulse to the discontinuity and back surface reflections is proportional to the elapsed time it takes for a pulse to travel through the material and the reflections to return. From the previous chapters we learned wave velocity in a material is a known constant. Therefore, the elapsed time also represents the thickness of the material.

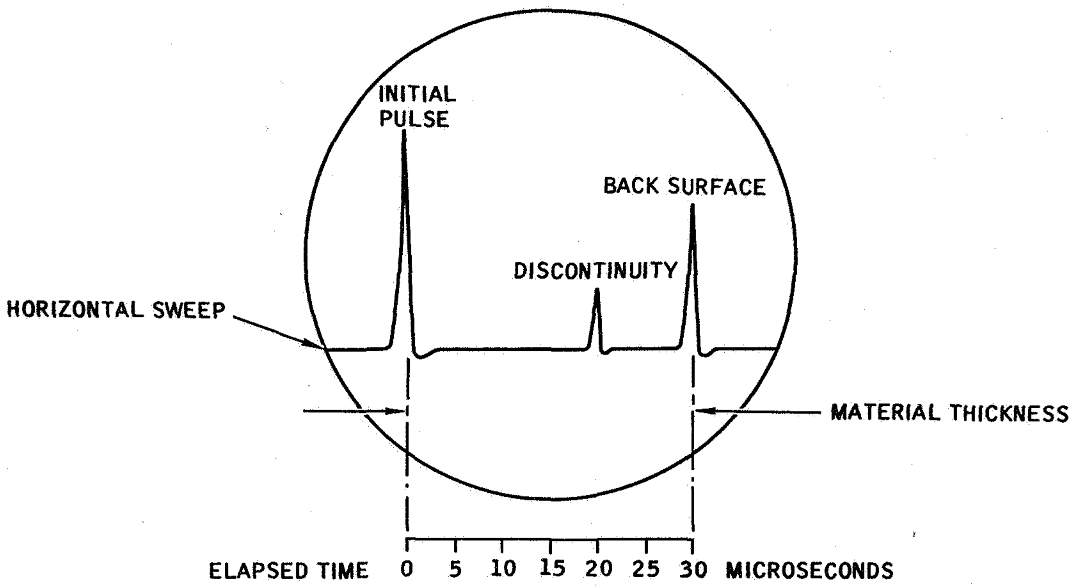
Let's say the above A-scan presentation represents a piece of steel three inches thick. The discontinuity is located...

approximately one inch below the surface .... Page 5-24

approximately two inches below the surface .... Page 5-25

From page 5-23

Incorrect. The example shows the discontinuity pip at two-thirds the distance between the initial pulse and the back surface reflection.



A-SCAN PRESENTATION

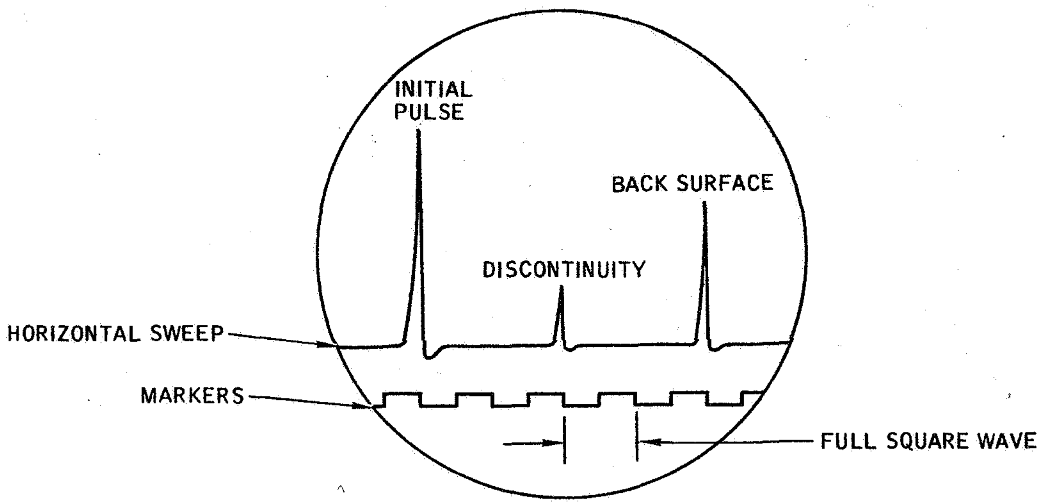
Remember the elapsed time or distance between the initial pulse and the back reflection represents the thickness of the material. If the material is three inches thick, wouldn't the depth of the discontinuity be two inches? Yes. Two-thirds of three inches is two inches.

Turn to page 5-25.

[redacted]

Right. The example A-scan presentation shows the discontinuity approximately two inches below the surface.

Some A-scan presentations include another display on the CRT screen. This display is usually in the form of square wave markers located below the horizontal sweep.



A-SCAN PRESENTATION

The square wave markers are used as units of time or distance and can be expanded or contracted as desired. We can adjust these markers to represent the distance between the initial pulse and back surface reflection in so many increments, inches, etc.

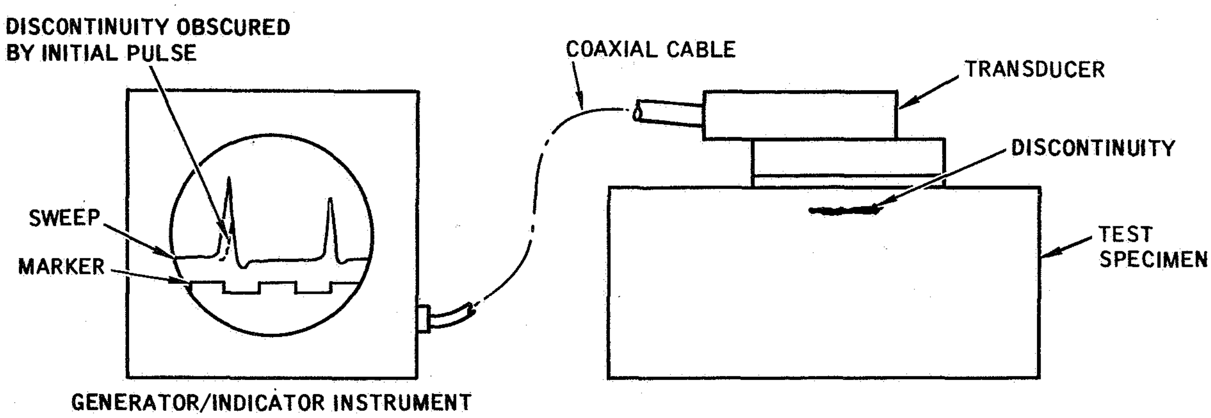
Let's say each full square wave in the above A-scan presentation represents one inch. The discontinuity is located...

two inches below the surface . . . . Page 5-26

four inches below the surface . . . . Page 5-27

Excellent! The given example shows the discontinuity two inches below the surface of the material.

At this point we should know the initial pulse may partially block or obscure discontinuity reflections from discontinuities directly under the transducer. This means that during part of the initial pulse the transducer is still transmitting and cannot receive reflections till its function as a transmitter is completed. This characteristic gives rise to an appreciable "dead zone" at the material's front surface where discontinuities cannot be detected.



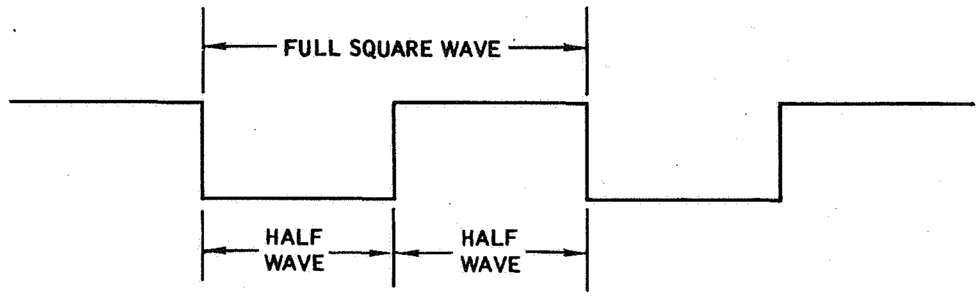
Select the best answer to the following statement. That area near the front surface of a test specimen where no reflections can be observed because of the inherent length of the transmitted pulse is known as the...

near zone . . . . Page 5-28

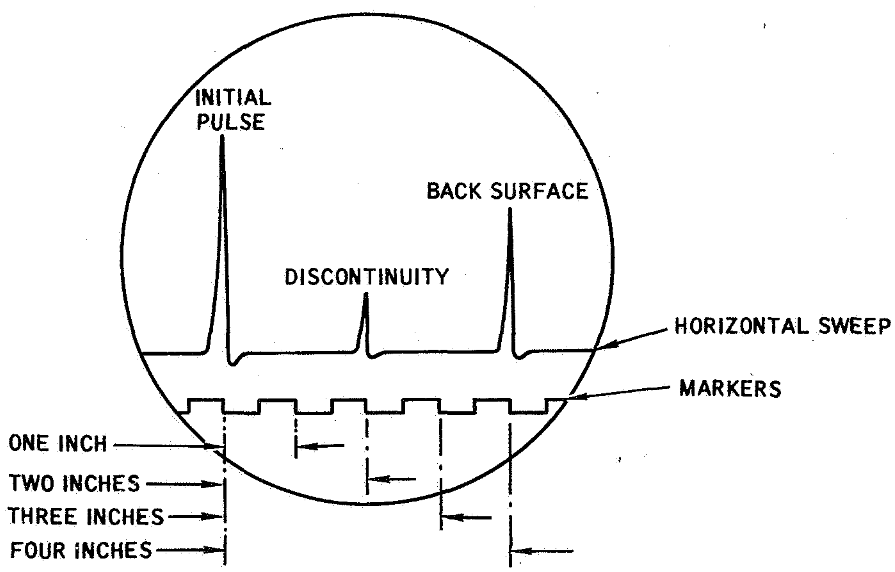
dead zone . . . . Page 5-29

From page 5-25

Four inches below the surface is not the correct answer for the given example. You apparently do not have the right idea of a square wave.



The above illustration shows that each segment represents a half wave. Two segments represent a full square wave.



Let's repeat the example of each square wave representing one inch. Are not two square waves shown between the initial pulse and the discontinuity? Yes. Can't we then say the discontinuity is two inches below the surface of the material being tested? Yes.

Turn to page 5-26.

[redacted]

From page 5-26

Incorrect. The DEAD ZONE is that area near the FRONT SURFACE of a test specimen where NO REFLECTIONS can be observed because of the INHERENT LENGTH of the TRANSMITTED PULSE.

We learned in Chapter 2 the "near zone" is that zone near the front surface containing irregular intensities. Wave energy is not uniform across the ultrasonic beam.

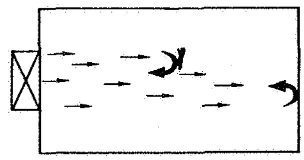
Turn to page 5-29.

From page 5-26

Good! The "dead zone" is that area of a specimen directly beneath its surface from which no reflections can be observed. Any reflections in the dead zone are obscured by the initial pulse.

Turn to page 5-30 for a review.

From page 5-29



1. The test system which uses reflected energy to find discontinuities is called the p__________e-e__________o system.

7. standing waves

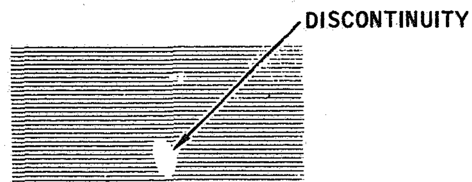
8. Standing waves cause the specimen to vibrate with (less) (greater) ______________ amplitude.

14. A-scan presentation

15. The A-scan presentation is read l_____t to r_______t.

21. length, depth

22. The C-scan presentation is a pl_________ v_________ indication similar to an X-_________ pic_______________.



1. pulse-echo

2. In the pulse-echo system, a single transducer is used (usually) as both the trans____________ter and rec____________er.

8. greater

9. An unaccountable change in res____________ ____________quency means a discontinuity.

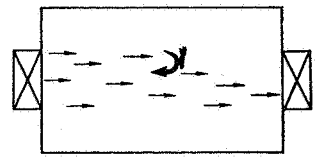
15. left, right

16. The first pip is the in________l pu________e while a discontinuity pip will be displayed anywhere between the first pip and the pip representing the back sur____________ refl_________n.

22. plan view, X-ray picture

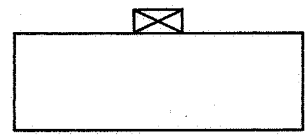
23. The contour or shape of a discontinuity is shown in the C-____________ p____________ion.

2. transmitter, receiver



3. The test system which uses variations in received energy amplitude to indicate discontinuities is called thr________h trans________________.

9. resonant frequency



10. In c__________tact testing, the transducer physically touches the test material.

16. initial pulse,
surface reflection

17. The height of a pip indicates wave amp_____________________ and the space between the pips represents ti_____________ or dis__________________.

23. C-scan presentation

24. That area beneath the front surface of a specimen from which no reflection can be observed is called the d_____________ z_____e.

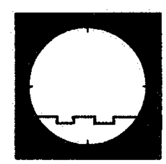
3. through transmission

4. In through transmission testing, (the same transducer) (separate transducers) ____________________ is/are used to transmit and receive energy.

10. contact

11. A thin film of coup__________ is used between the transducer and test specimen in contact testing.

17. amplitude, time, distance



18. M________kers are used to show units of time or distance.

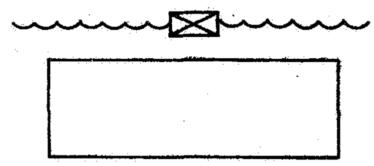
24. dead zone

25. Reflections from the dead zone are obscured by the ini__________ p__________.

4. separate transducers

5. The pulse-echo system uses only (pulsed) (continuous) ______________ wave trains, while the through transmission system can use (only continuous) (either continuous or pulsed) ______________ wave trains.

11. couplant



12. The transducer does not physically touch the test material (specimen) in im__________sion __________sting.

18. Markers

19. The markers are usually in the form of a sq__________w__________e located directly below the horiz__________sw__________p.

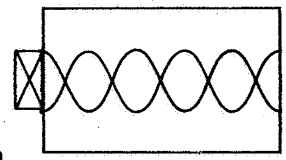
25. initial pulse

26. Turn to page 6-1.

[redacted]

5. pulsed, either continuous or pulsed

6. Continuous longitudinal waves are transmitted into material when using the r__________ ance test system.

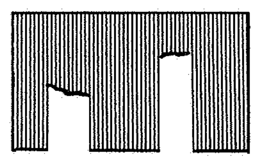


12. immersion testing

13. Immersion testing is where both the transducer and the test specimen (usually) are placed in a liq____________ ____________ plant.

19. square wave, horizontal sweep

20. The display which shows a cross-sectional view of the test specimen is known as the _________-scan pre__________________tion.

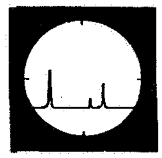


6. resonance

7. In the resonance system, the transmitted wave frequency is varied till stan__________g wav______ are set up in the material.

Return to page 5-30, frame 8

13. liquid couplant



14. The CRT display which uses "pips" for indications is known as the ______-scan pre____________n.

Return to page 5-30, frame 15

20. B-scan presentation

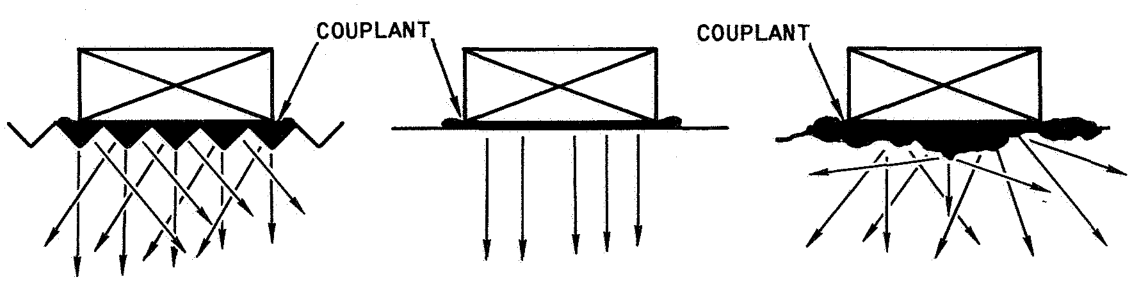
21. The B-scan presentation pictorially shows the l_______________ and d_______th of a discontinuity.

Return to page 5-30, frame 22

In the preceding chapters you learned the basic concepts of ultrasonic waves and how they're generated and propagated through materials. You learned the basic principles of the different test systems and methods used as well as the types of visual presentations encountered. In this chapter you will learn how a specimen's surface condition, shape, and internal structure affect ultrasonic waves. You also will be able to recognize various types of discontinuities as displayed in the A-scan presentation.

The patterns as seen in an A-scan presentation are usually not as simple as those shown in the preceding chapter. An indication in one case may mean something quite different in another. You may find yourself concentrating on indications that have no significance whatever. However, as you gain experience, you will learn how to recognize these irrelevant indications and be able to use them or ignore them as the case may be.

The surface condition of a specimen greatly influences the transmitting and receiving of ultrasonic energy. Rough surfaces can cause several undesirable effects, including (1) loss of discontinuity and back surface amplitude, (2) increased width of the front surface indication and consequent loss of resolving power, (3) distortion of wave directivity, and (4) spurious generation of surface waves. The effects of various surfaces are shown below.



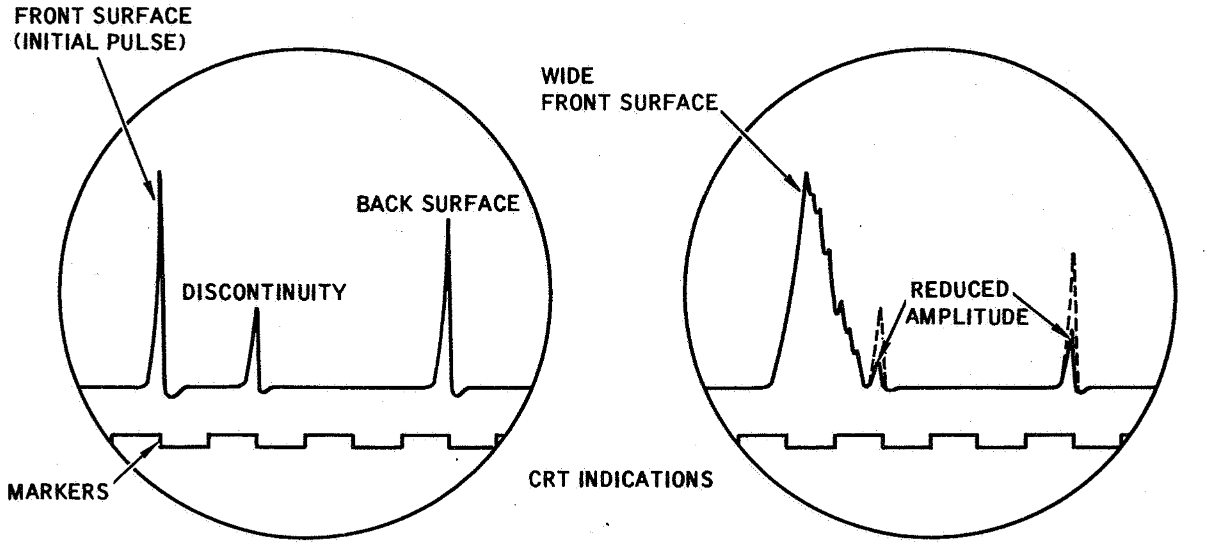
UNEVEN BUT CONSISTANT SURFACE
FAIR

FLAT SMOOTH SURFACE
BEST

ROUGH AND IRREGULAR SURFACE
POOR

Turn to page 6-2.

From page 6-1



FLAT SMOOTH SURFACE - GOOD RESPONSE   ROUGH AND IRREGULAR SURFACE - POOR RESPONSE

A-SCAN PRESENTATION
(PULSE-ECHO)

For reliable testing it is highly desirable that the coupling of the transducer to the specimen be as uniform as possible.

Can we say a specimen's surface condition is an important factor in ultrasonic testing?

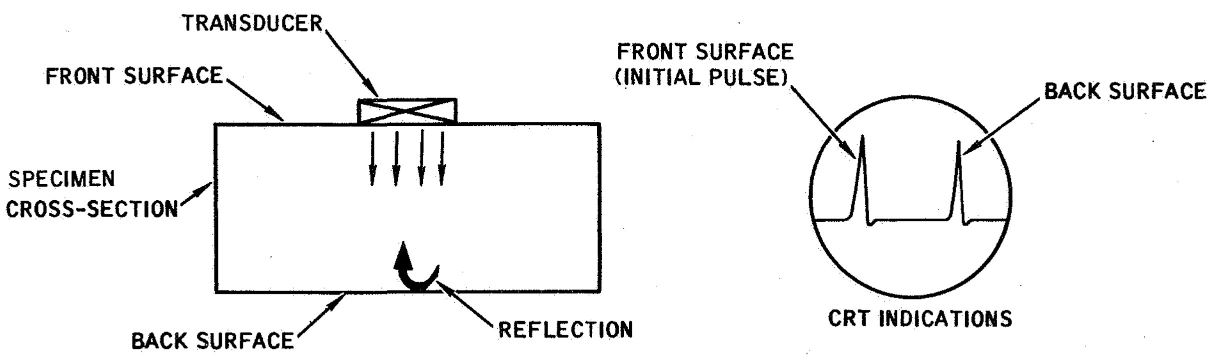
Yes . . . . Page 6-3

Makes no difference . . . . Page 6-4

From page 6-2

Right. A specimen's surface condition is an important factor in ultrasonic testing. In fact if a specimen's surface is too uneven or rough, ultrasonic testing may prove to be impractical.

The impact of ultrasonic waves at the boundary of a specimen can be compared to the reflection of visible light. If the beam incidence is perpendicular to the boundary, it is reflected back to its source similar to light striking a mirror. An ideal specimen shape for distinguishing discontinuities is where the front and back surfaces are parallel. In the pulse-echo system for example, the transmitted energy is reflected directly back to the transducer. Wave propagation is direct and we have the least amount of attenuation. A good back surface reflection indicates a good response from the material being tested.



PARALLEL SURFACES
(PULSE-ECHO)

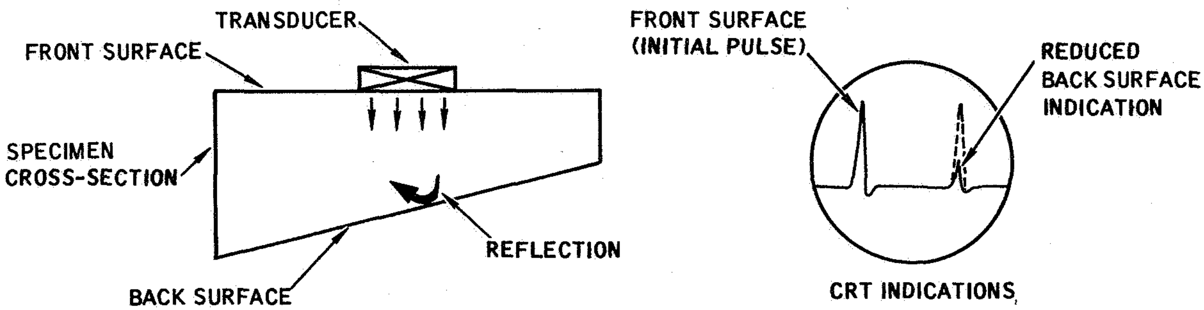
Turn to page 6-5.

Incorrect. Surface condition does make a difference. A flat smooth surface is better for ultrasonic testing than one that is uneven or rough. Remember that the rougher the surface, the more difficult it is to obtain a reliable response from the specimen.

Turn to page 6-3.

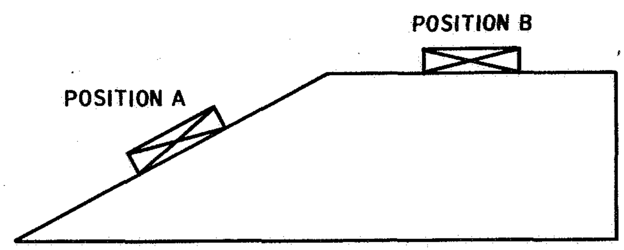
From page 6-3

If the surfaces are not parallel, the reflected energy will be directed away from the transducer similar to light falling on a mirror at an angle, reducing the received response. In some cases a complete loss of the back surface reflection is possible depending on the angle of reflection.



ANGULAR SURFACES
(PULSE-ECHO)

Which transducer position shown below will provide the best back surface indication on a CRT?

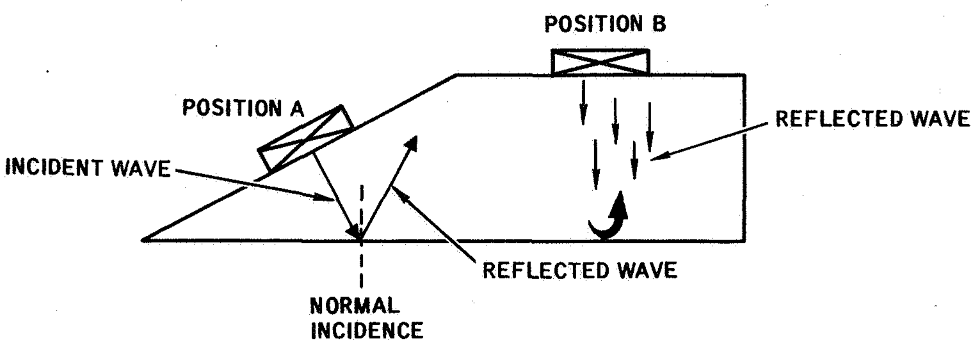


Position A . . . . Page 6-6
Position B . . . . Page 6-7

From page 6-5

You are not right. The transducer shown at position B will provide the best back surface indication.

We learned in Chapter 3 that an incident wave which strikes a surface at an angle will be reflected at an angle equal to the angle of incidence as shown below at position A.

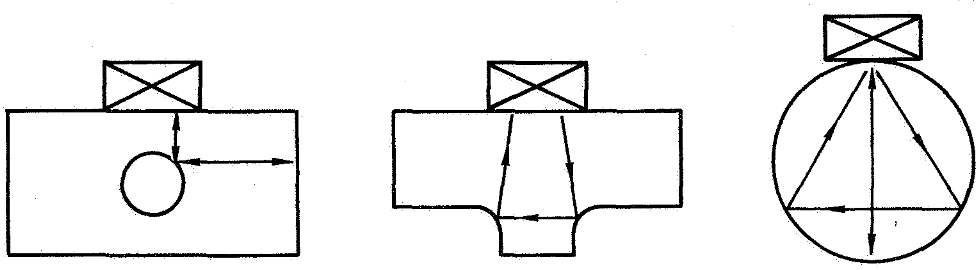


Won't the reflected wave at position A miss the transducer? Yes. Isn't the wave at position B reflected directly back to the transducer? Yes. Therefore, won't the transducer at position B provide the best back surface indication? Yes.

Turn to page 6-7.

Right. The transducer shown at position B in the example will provide the best back surface indication.

Angular or contoured surfaces may create CRT indications which may be confused as indications from discontinuities. These spurious indications result from sound being reflected from a specimen's boundaries and back to the transducer at a time equivalent to the length of time necessary for the sound to travel from a discontinuity to the transducer.



EXAMPLES OF SOUND PATHS LEADING TO SPURIOUS INDICATIONS

Which of the following statements is true?

A specimen's physical shape or contour need not be considered when attempting to discern whether a discontinuity indication is real or false . . . . Page 6-8

A specimen's physical shape or contour must be considered when attempting to discern whether a discontinuity indication is real or false . . . . Page 6-9

Wrong. A specimen's physical shape or contour must be considered when attempting to discern whether a discontinuity indication is real or false. We must decide whether or not a particular indication is the result of a wave striking a radius or fillet, etc., and reflecting back to the transducer before the back surface indication. Reflections between any angular surfaces could cause spurious indications on the CRT screen.

Turn to page 6-9.

Good. A specimen's physical shape or contour <u>must</u> be considered when attempting to discern whether a discontinuity indication is real or false.

Angular surfaces also cause mode conversion within the specimen. A part of the incident wave instead of being reflected at an angle equal to the angle of incidence is changed into another wave form and reflected at a different angle. In fact a reflected wave may change its mode from one type to another several times till its energy is expended, thus creating many reflections in the specimen. Any reflections that are in the same mode as the transmitted wave and which manage to reach the receiving transducer will form spurious indications of varying amplitudes on the CRT.

Is the following statement true or false?

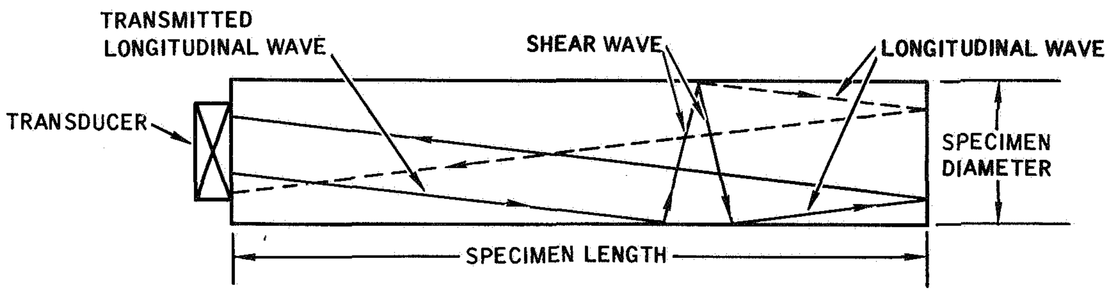
Mode conversion within a specimen is an important factor in considering whether a discontinuity indication is authentic or false.

True . . . . Page 6-10

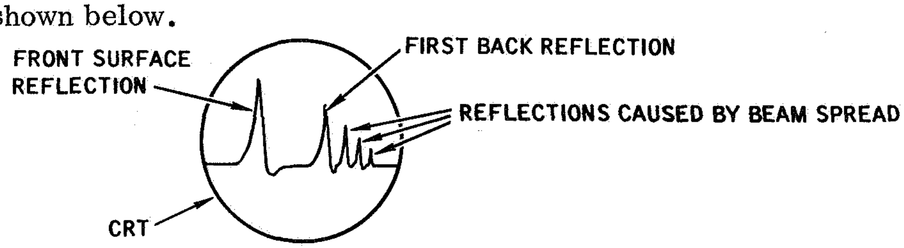
False . . . . Page 6-12

You're right. Mode conversion within a specimen is an important factor in considering whether a discontinuity indication is authentic or false.

In testing long specimens, reflection of a spreading sound beam can produce spurious indications on the CRT. These indications are the result of the edges of a sound beam striking the sides of the specimen and creating additional reflections through mode conversion. For example, as a longitudinal wave is transmitted into a specimen, part of it may hit the side of the specimen as shown below.



A shear wave is generated and reflected at a steep angle to the opposite side of the specimen where it is reflected again. This action continues till the energy is either absorbed by the specimen or reflected back to the transducer. It is obvious the reflections from the waves created through mode conversion have longer paths to travel back to the transducer than the main wave reflection. Therefore, any reflections resulting from beam spread will appear on the CRT screen to the right of the first back surface reflection as shown below.



The additional reflections will appear at regular intervals with diminishing amplitudes following the first back surface reflection. Note the distance between the front surface reflection and the back surface reflection as compared to the distance between the back surface and the wave reflections caused by beam spread.

Can the beam spread wave reflections shown above be mistaken for discontinuities?

Yes . . . . Page 6-11

No . . . . Page 6-13

You are incorrect. The wave reflections caused by beam spread cannot be mistaken for discontinuities. Didn't we learn in Chapter 5 that a discontinuity indication will appear between the front surface "pip" and the first back surface "pip"? Yes. Since the indications appear to the right of the first back surface reflection, we can ignore them.

Turn to page 6-13.

From page 6-9

Your choice of "False" is the incorrect answer. Mode conversion within a specimen is an important factor in considering whether or not a discontinuity indication is real or false.

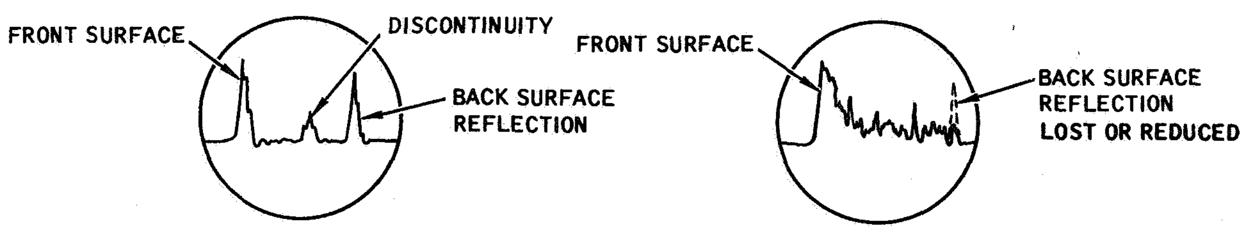
Because refraction occurs when a wave strikes a boundary at an angle, additional reflections are created which under certain conditions can reach the receiving transducer. These refracted wave reflections can be confusing in that you might be led to think they are a discontinuity.

Turn to page 6-10.

From page 6-10

Correct. The wave reflections caused by beam spread, as shown in the example, can be ignored. Generally, we are interested in only those indications which appear between the front and back surface "pips".

Grain structure is of great influence on the acoustical properties of a material. A high alloy steel forging for example has a fine grain structure and a very low damping of sound. A casting on the other hand has a coarse grain structure and is very difficult to get any sound through. Sound propagation is also influenced by the orientation of the grain structure. The following CRT presentations show the effect of material grain structures on discontinuity indications.



FINE GRAIN COARSE GRAIN

Note that the coarse grain structure appears as multiple irregular reflections sometimes called "grass", "hash", or "metal noise". The fine grain structure has a relatively clean pattern with sharp front and back surface indications.

Select the best answer to the following statement. It is extremely difficult to differentiate between discontinuity and structural indications in...

materials having fine grain structure . . . . Page 6-14

materials having a coarse grain structure . . . . Page 6-15

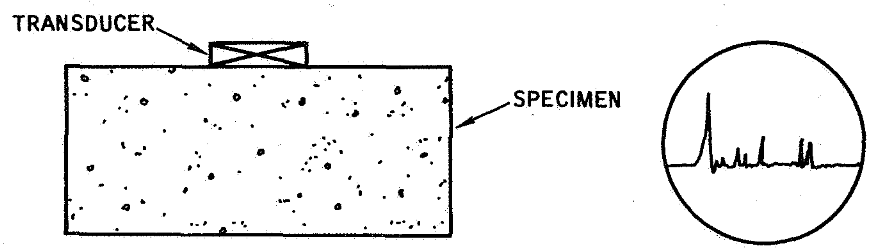
Incorrect. It is extremely difficult to differentiate between discontinuity and structural indications in materials having <u>coarse grain structure</u>. Remember the multiple irregular reflections from a coarse grain structure tend to obscure any discontinuity indications that may be present between the front and back surface indications.

Turn to page 6-15.

From page 6-13

Yes. It is extremely difficult to differentiate between discontinuity and structural indications in materials having coarse grain structure.

Materials having excessive fine porosity also present CRT patterns similar to that of coarse grain structure.



POROSITY INDICATION

A reduction or loss of the back surface indication occurs and many discontinuity indications of varying amplitude appear on the CRT.

Which of the following statements is true?

Fine porosity, like a coarse grain structure, appears on the CRT as many irregular reflections of varying amplitude accompanied by an increase in back surface height . . . . Page 6-16

Fine porosity, like coarse grain structure, appears on the CRT as many irregular reflections accompanied by a decrease in back surface amplitude . . . . Page 6-17

Wrong. It is true that fine porosity appears on the CRT as many irregular reflections of varying amplitude however the back surface indication will DECREASE, not increase. Remember that porosity acts like many reflectors and thereby reduces the amount of energy reaching the back surface of the specimen. The net effect is a reduction in back surface amplitude.

Turn to page 6-17.

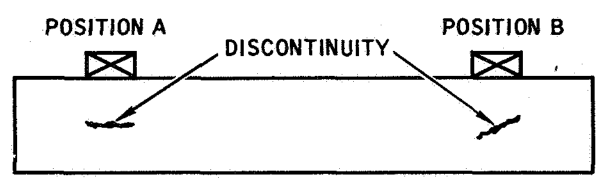
From page 6-15

You are right. Fine porosity, like coarse grain structure, appears on the CRT as many irregular reflections accompanied by a decrease in back surface amplitude.

In Chapter 5 we learned the distance between the front (initial pulse) and back surface indications on a CRT represents the elapsed time it takes for a pulse to travel through the specimen and return. By relating elapsed time to material thickness, we can find the depth of a discontinuity by noting its location between the front and back surface indications. We also found we can estimate the size of a discontinuity by comparing its amplitude with that of a known discontinuity.

Now you shall learn how a discontinuity's orientation to the front surface may cause variations in depth and size indications. When a discontinuity is not normal (at 90-degree angle) to the incident wave, that portion of the wave reflected by the discontinuity is reflected at an angle. This angle can be such that part of the discontinuity reflection will not return to the transducer. The net result is a reduction in the amplitude of the discontinuity indication displayed on the CRT.

In an A-scan presentation, which transducer position shown below will provide the greatest amplitude (height) indication?

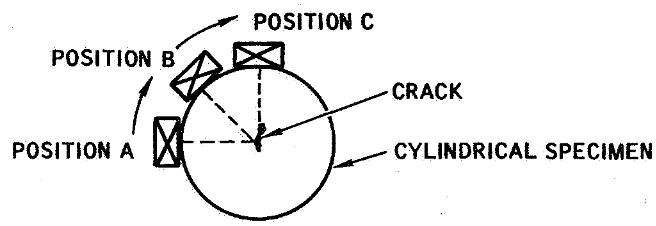


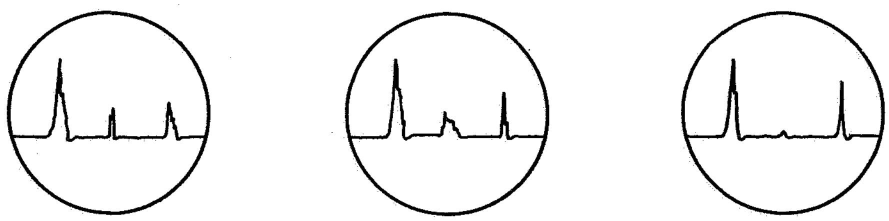
Position A . . . . Page 6-18

Position B . . . . Page 6-21

Correct. The transducer shown at position A will provide the greatest amplitude indication.

Now let's transmit ultrasonic waves into a cylinder containing a narrow crack-like discontinuity and observe the effects.





POSITION A POSITION B POSITION C

At position A we obtain a maximum amplitude discontinuity indication as the waves are normal to the surface of the discontinuity. We have a sharp discontinuity indication and a fairly low amplitude back surface indication. As the transducer is moved toward position B, the amplitude of the discontinuity indication will decrease and the amplitude of the back surface indication may tend to increase slightly as a larger part of the incident waves gets past the discontinuity. At position C, the discontinuity indication is at its minimum. In fact if the discontinuity is very narrow, no discontinuity indication may appear at all and the back surface indication may have an amplitude like that from a sound specimen. Note that at position B, the discontinuity not only decreases in amplitude on the CRT but tends to spread out over a longer time period.

Is the following statement true or false? The orientation of a discontinuity's surface plays an important part in detection and size estimation.

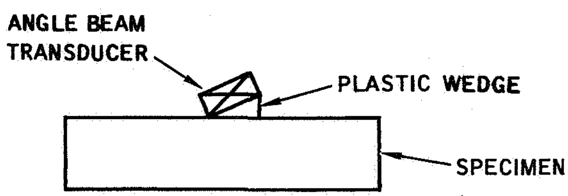
True . . . . Page 6-19

False . . . . Page 6-20

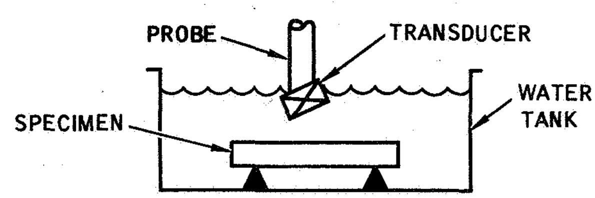
Very Good! It is true that surface orientation plays an important part in detecting and estimating the size of a discontinuity.

The amplitude of a discontinuity indication depends upon both the angle of the discontinuity surface as well as its size. As we just learned, an angle can be eventually reached where all the energy striking the discontinuity will reflect to a surface other than the surface directly under the transducer.

Two basic techniques are used in locating and evaluating angular discontinuities.



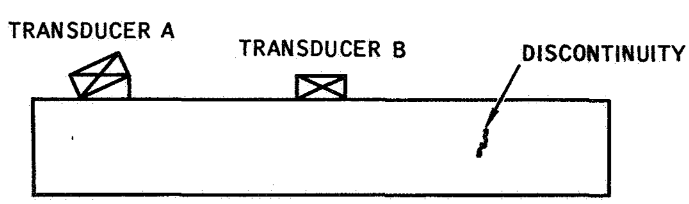
CONTACT TESTING



IMMERSION TESTING

In contact testing we use an "angle beam" transducer incorporating a plastic wedge or similar device to change the direction of wave propagation. In immersion testing, we simply tilt the transducer. Through mode conversion and refraction, the direction of wave propagation is altered to locate discontinuities which otherwise might be missed.

Shown below is a long specimen containing a crack-like discontinuity oriented perpendicular to the front surface. Which transducer would you use to inspect for the presence of a discontinuity oriented as such?



Transducer A . . . . Page 6-22

Transducer B . . . . Page 6-23

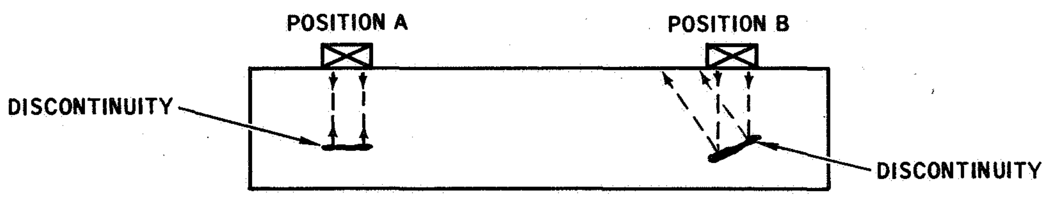
You chose the incorrect answer. The orientation of a discontinuity DOES play an important part in its detection and size estimation.

Didn't we find by rotating a transducer around a crack-like discontinuity, its amplitude would increase or decrease with respect to the angle of incidence? Yes. Couldn't this affect size estimation? Yes. Can't we have a condition where a discontinuity indication may not appear on the CRT screen because of orientation? Yes. We must be aware of these orientation effects to properly evaluate a CRT pattern.

Turn to page 6-19.

You chose the incorrect answer. The transducer shown at position A provides the greatest amplitude indication.

Discontinuities act like material surfaces or boundaries. That part of an incident wave reflected by the surface of a discontinuity is reflected at an angle equal to the angle of incidence. Therefore at position B, part of the reflected wave will miss the transducer and thus result in a lower amplitude indication. The discontinuity at position A is perpendicular to the incident wave. Its reflection follows the same path as the incident wave resulting in a greater amplitude indication.



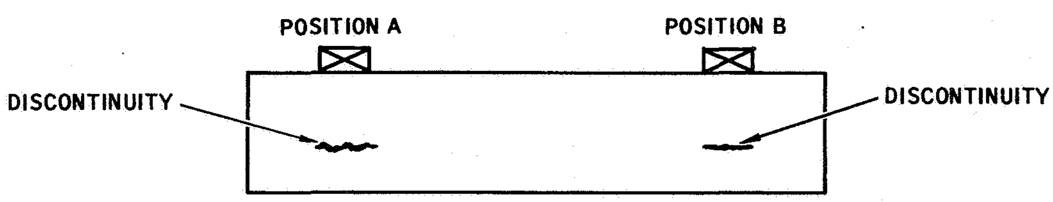
Turn to page 6-18.

From page 6-19

Excellent! We would use the "angle beam" transducer identified as transducer A to find crack-like discontinuities perpendicular to the front surface.

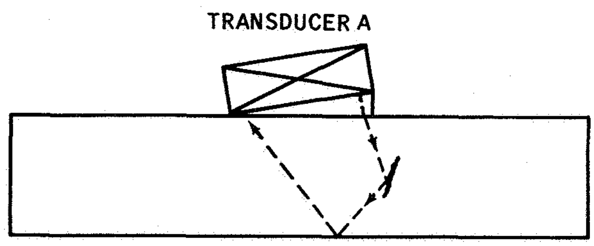
The shape or surface condition of a discontinuity influences discontinuity indications in much the same manner as interfaces or material boundaries affect transmission and receiving of ultrasonic energy. A discontinuity having a rough surface will tend to scatter its reflection where a smooth surface will reflect a more refined beam. The affect of a rough surfaced discontinuity is a discontinuity indication of reduced amplitude compared to a smooth surfaced discontinuity of the same size.

In an A-scan presentation, which transducer position shown below will provide the greatest amplitude (height) indication?



Position A . . . . Page 6-24
Position B . . . . Page 6-25

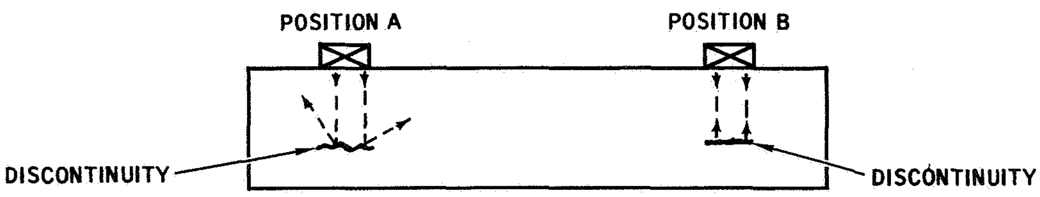
Incorrect. Transducer B will transmit only waves perpendicular to the front surface of the specimen. If the discontinuity is also perpendicular as shown in the example, the waves may bypass the discontinuity and no discontinuity indication will appear on the CRT. Transducer A (the correct answer) transmits waves at an angle through a plastic wedge. These angulated waves will strike the discontinuity and appear as a discontinuity indication on the CRT.



Turn to page 6-22.

Incorrect. The transducer shown at position B will provide the greatest amplitude indication.

The discontinuity shown at position A is rougher than the one at position B. Didn't we find a rough surface discontinuity will scatter its reflection and reduce its amplitude? Yes. The reflected energy at position B travels a direct path back to the surface under the transducer; therefore, it will have the greatest amplitude.



Turn to page 6-25.

Correct. The discontinuity at position B will provide the greatest amplitude indication.

Variations in impedance affect the amplitude of a discontinuity indication. For example a crack, void or seam acts like a material boundary and has a very high impedance ratio. We get total reflection from the discontinuity. Slag which is a nonmetallic inclusion has an impedance closer to that of the specimen material. We find some energy will propagate through a nonmetallic inclusion and continue on to the back surface of the specimen where it is reflected.

Select the best completion for the following statement.

For a given size discontinuity, nonmetallic inclusions produce discontinuity indications having . . .

greater amplitude than a crack-like discontinuity or void . . . . Page 6-26

less amplitude than a crack-like discontinuity or void . . . . Page 6-27

You chose the incorrect answer. For a given size discontinuity, nonmetallic inclusions produce discontinuity indications having less amplitude than a crack-like discontinuity or void.

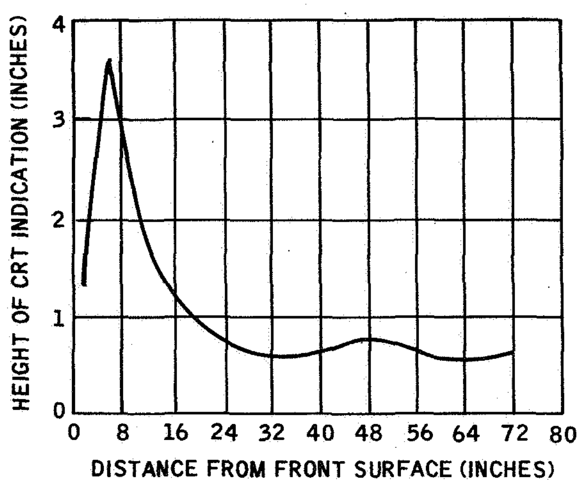
Remember impedance ratio determines the amount of energy transmission and reflection at a discontinuity. The higher the ratio, the greater the reflection. The lower the ratio, the smaller the reflection.

Turn to page 6-27.

From page 6-25

Right. For a given size discontinuity, nonmetallic inclusions produce discontinuity indications having less amplitude than a crack-like discontinuity or void.

The effect of distance on discontinuity amplitude is also appreciable. As shown below, when height (amplitude) is plotted against distance from a specimen's front surface, we find the height first increases with increasing distance to a maximum value and then decays almost exponentially.



EFFECT OF DISTANCE ON INDICATION HEIGHT-TYPICAL

To further define the distance-amplitude effect, a discontinuity for example six inches from a specimen's front surface might give an indication twice as high as a discontinuity of the same size located two inches or 17 inches from the front surface.

Select the best completion for the following statement.

The amplitude of a discontinuity indication in relation to depth . . .

steadily decreases as depth increases . . . . Page 6-28

may vary as depth increases . . . . Page 6-29

Wrong. The amplitude of a discontinuity indication in relation to depth VARIES as depth increases. This relationship is a fact we must keep in mind when evaluating discontinuities.

Turn to page 6-29.

Correct! The amplitude of a discontinuity indication in relation to depth varies as depth increases. The extent of this relationship also may vary considerably from one material to another.

In summation we have learned the following factors affect discontinuity size indications:

- Orientation of discontinuity in relation to specimen front surface.
- Surface condition of discontinuity.
- Impedance of discontinuity.
- Depth of discontinuity.

Turn to page 6-30 for a review.

From page 6-29

1. An important factor in coupling the transducer to the specimen is specimen surf______ con______on.

5. amplitude

6. Be__m sp_____ in long specimens may cause spurious indications through mode conversion.

10. discontinuities, amplitude

11. Discontinuities will cause a reduction or complete loss of the b________ s________ indication, depending on the size of the discontinuity.

15. rough

16. The amplitude of a smooth surface discontinuity is (greater) (less) ______________ than one from a rough surface.

1. surface condition

2. Rough surfaces may block sound propa________ or cause spurious disc_________ty indications on the cathode-ray tube (CRT).

6. Beam spread

7. Discontinuity indications appearing to the (left) (right)___________ of the first back surface reflection are spurious or false indications and can be ignored.

11. back surface

12. The detection of a discontinuity sometimes depends on its surface ori____________n.

16. greater

17. Nonmetallic inclusions produce reflections having (less) (greater) __________ amplitude than similar size cracks or voids.

2. propagation,
discontinuity

3. The ideal specimen shape or geometry is one where the front and back surfaces are (at an angle) (parallel) ________________.

7. right

8. Materials with (coarse) (fine) __________ grain structure are difficult to test.

12. orientation

13. In contact testing, (straight beam) (angle beam) ____________ transducers are used to find or evaluate discontinuities orientated other than parallel to the specimen's surface.

17. less

18. The amplitude for a given size discontinuity will vary with increasing d___th.

[redacted])

3. parallel

4. Irregular shaped specimens may create (false) (high amplitude)______________ ____________________ discontinuity indications.

8. coarse

9. Coarse grain structure causes multiple irreg______ar in_______ons to appear between the front and back surface indications on a CRT which tend to obscure discontinuity indications.

13. angle beam

14. In immersion testing, we angulate or tilt the tran_________ to find or evaluate discontinuities orientated other than parallel to the specimen's surface.

18. depth

19. Now let's turn to page 6-35.

4. false

5. Ultrasonic waves reflected from an angular surface may result in a reduction or complete loss of indication amp________e.

Return to page 6-30, frame 6

9. irregular indications

10. Fine porosity appears on a CRT screen as many dis______s of varying amp______.

Return to page 6-30, frame 11

14. transducer

15. The reflection from a (smooth) (rough)_________surfaced discontinuity scatters.

Return to page 6-30, frame 16

From page 6-33

Congratulations! You have just completed the first volume of the programmed instruction course on ultrasonic testing.

Now you may want to evaluate your knowledge of the material presented in this handbook. A set of self-test questions are included at the end of the book. The answers can be found at the end of the test.

We want to emphasize that the test is for <u>your own</u> evaluation of <u>your</u> knowledge of the subject. If you elect to take the test, be honest with yourself — don't refer to the answers till you have finished. Then you will have a meaningful measure of your knowledge.

Since it is a self evaluation, there is no grade - no passing score. If you find that you have trouble in some part of the test, it is up to you to review the material till you are satisfied that you know it.

Turn or rotate the book 180° and flip to page T-1.

53[redacted]

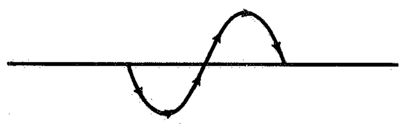
ULTRASONIC TESTING - VOLUME I - BASIC PRINCIPLES

Self-Test

1. In ultrasonic testing, energy is transmitted through a solid material by a series of small material displacements within the material. (True - False) __________.

2. The condition of starting at a center position, moving towards a maximum position, returning through the center position to a maximum position in the opposite direction, and finally returning to the center position is called a ______________________.

    a. Frequency
    b. Period

    c. Cycle
    d. Wavelength

3. The back and forth movements of particles within a medium are called ______________________.

    a. Cycles
    b. Wavelengths
    c. Vibrations
    d. Displacements

4. The time required to perform one complete cycle is called the ______________.

    a. Period
    b. Frequency
    c. Wavelength
    d. Velocity

5. The number of cycles per second (cps) a vibration occurs is called the ________________.

    a. Period
    b. Frequency
    c. Wavelength
    d. Velocity

6. The movement of a particle away from its center (rest) position is called a ________________.

    a. Cycle
    b. Vibration
    c. Wavelength
    d. Displacement

7. Vibrations in solid materials do not represent energy in motion. (True - False) ________________

8. A vibration can be said to have the following property: ____________________.

    a. Cycle
    b. Period
    c. Frequency
    d. All of these

9. Ultrasonic sound propagates through a medium as waves of particle vibrations. (True - False) ________________

10. The words "waves", "beam", and "sound" are used interchangeably in ultrasonic testing. (True - False) ________________

11. Ultrasonic sound is usually described as sound ____________________________.

    a. Which may or may not be heard by human ear
    b. Too high to be heard by human ear
    c. Too low to be heard by human ear
    d. Which can be heard in the audible range only

12. The velocity of sound is constant for a given material but varies from one material to another material. (True - False) ________________

13. Ultrasonic vibrations are generally defined as having a frequency above ________________.

    a. 5,000 cps
    b. 20,000 cps
    c. 100,000 cps
    d. 1,000,000 cps

14. Ultrasonic sound can be either continuous or pulsed. (True - False) __________.

15. Ultrasonic sound moves through solids as well as ________________.

    a. Air
    b. Liquids
    c. Grease
    d. All of these

16. Wavelength is defined as ____________________________________.

    a. The distance a wave travels to the back surface of the specimen
    b. The distance a waveform advances while a particle makes one complete vibration or orbit
    c. The number of cycles produced per second
    d. The time required for a wave to reach a certain point in the specimen.

17. Wave velocity is dependent on ____________________________________.

    a. The ratio of sound velocity to wavelength
    b. The density and elastic properties of the medium
    c. The material density and frequency in the medium
    d. The elasticity of the medium through which the wave is traveling

18. Transducers used in ultrasonic testing exhibit which of the following effects? ________________.

    a. Ferromagnetic
    b. Piezoelectric
    c. Electromechanical
    d. Hyperacoustic

19. Transducer bandwidth is dependent on its central frequency ________________.

    a. Wavelength
    b. Velocity
    c. Waveform
    d. Amplitude

20. A definite relationship exists among the three factors; velocity, frequency, and wavelength. This relationship is expressed by the formula ________________.

    a. $\lambda = v/f$
    b. $\lambda = f/v$
    c. $\lambda = fv$
    d. $x = \lambda/f$

21. If frequency is increased, the wavelength will ________________ ________________.

    a. Decrease (be shorter)
    b. Increase (be longer)
    c. Will remain the same but velocity will increase
    d. Will remain the same but velocity will decrease

22. A device that converts electrical energy to mechanical energy and mechanical energy to electrical energy is called a ________________.

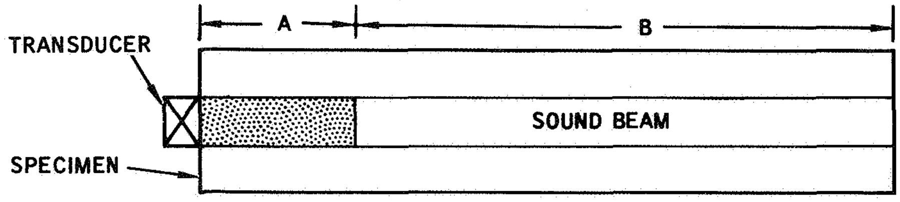
    a. Generator
    b. Transceiver
    c. Transducer
    d. Converter

23. Ultrasonic sound in a solid material is usually a broad, expanding beam of mechanical energy. (True - False) ________________

24. The zone in an ultrasonic beam where irregular intensities exist is called the ________________.

    a. Near zone
    b. Far zone
    c. Irregular zone
    d. Free field

25. In the adjacent figure, zone A is called the ________________________.



a. Near zone
b. Far zone
c. Irregular zone
d. Free field

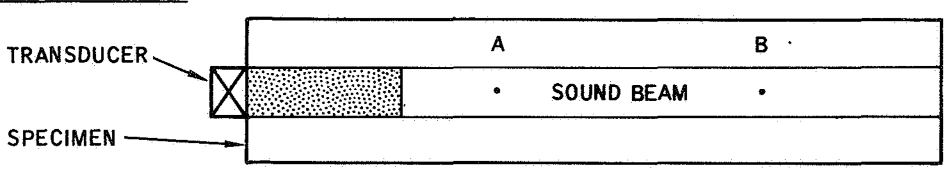
26. In the preceding figure, zone B is called the ________________________.

a. Near zone
b. Far zone
c. Irregular zone
d. Free field

27. When the beam spread of an ultrasonic beam is small, the intensity across the beam is said to ________________________.

a. Be relatively constant
b. Decrease in intensity
c. Increase in intensity
d. Both increase and decrease in intensity with depth

28. In the adjacent figure, the intensity at point B will be the same as at point A. (True - False) __________



29. As frequency increases in ultrasonic testing, beam spread (divergence) for a given diameter transducer ________________.

a. Decreases
b. Remains unchanged
c. Increases
d. Varies uniformly

30. The loss of energy as sound moves through a specimen is called __________.

a. Absorption
b. Propagation
c. Reflection
d. Attenuation

31. Acoustical impedance is defined as ________________________ ________________.

a. The product of material density and wave velocity
b. The ratio of material density to wave velocity
c. The ratio of wave velocity to sound density
d. The product of wave velocity and frequency

32. The relationship of acoustical impedance to material density and wave velocity is expressed by the formula ________________.

a. $Z = \lambda V$
b. $Z = pV$
c. $Z = p/V$
d. $Z = V/p$

33. The lower the impedance ratio is between materials making up an interface, the greater the sound loss. (True - False)

34. The purpose of a couplant is to ________________.

a. Filter undesirable reflections from the specimen
b. Tune the transducer to the correct operating frequency
c. Reduce attenuation within the specimen
d. Transmit ultrasonic waves from the transducer to the specimen

35. A couplant can be ________________.

a. Water
b. Oil
c. A plastic material
d. All of these

36. The useful width of the sound beam emitted from a transducer is ________________.

a. Less than the transducer's physical width
b. The same as the transducer's physical width
c. Increased by the side or secondary lobe effect

37. A small diameter transducer will produce the smallest amount of beam spread for a given frequency. (True - False) ________________

38. Any differences in acoustic impedance between adjacent media produce ________________.

a. Refraction
b. Propagation
c. Reflection
d. Attenuation

39. Which of the following cannot be considered a coupling agent? ________________

a. Grease
b. Water
c. Air
d. Glycerin

40. A transducer is capable of radiating any impressed frequency within its band. (True - False) ________________

41. Snell's Law is used to find ______________________________.

a. Critical angles
b. Angular relationships
c. Velocity
d. Wavelength

42. The formula expressing the angle of refraction of a sound beam passing from one material to another is __________________________________.

a. $\frac{\sin \phi_1}{\sin \phi_2} = V_1 V_2$
b. $\lambda = v/f$
c. $Z = pV$
d. $\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2}$

43. The angle of reflection of an ultrasonic beam is ______________________________ ________________.

a. Equal to the angle of incidence
b. Approximately four times the angle of incidence
c. Approximately half the angle of incidence
d. Equal to the angle of refraction

44. Longitudinal (compression) waves produce vibrations which are _______________ ____.

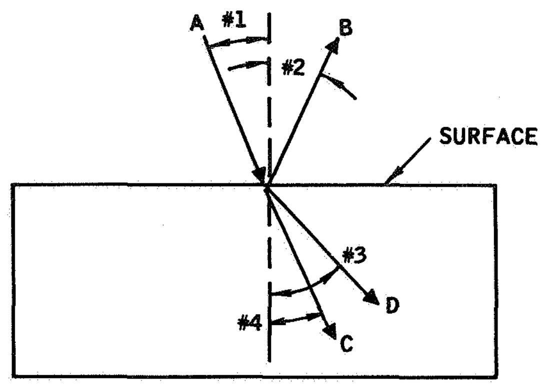
a. In the same direction as the motion of the sound
b. Perpendicular to the motion of the sound
c. Elliptical
d. Symmetrical

45. Shear or transverse waves are described as having ____________________________ ____.

a. Particle motion normal (90°) to direction of propagation and a velocity approximately half that of longitudinal waves.
b. Exceptionally high sensitivity due to low attenuation resulting from longer wavelengths when propagating through water
c. A velocity approximately twice that of surface waves in the direction of propagation
d. Particle motion perpendicular (90°) to the direction of propagation and no attenuation in water

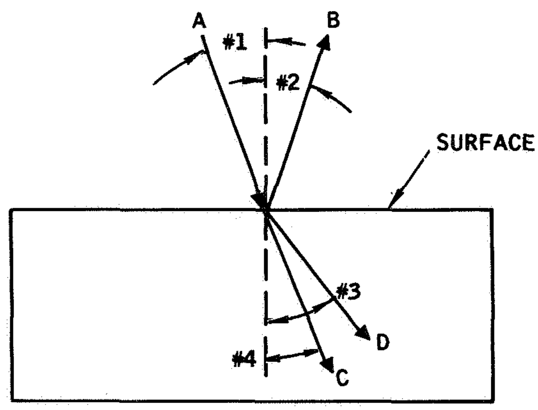
46. The adjacent figure illustrates four waves. Wave A strikes the surface of the specimen and produces waves B, C, and D. The incident angle is ________.

a. #1
b. #2
c. #3
d. #4



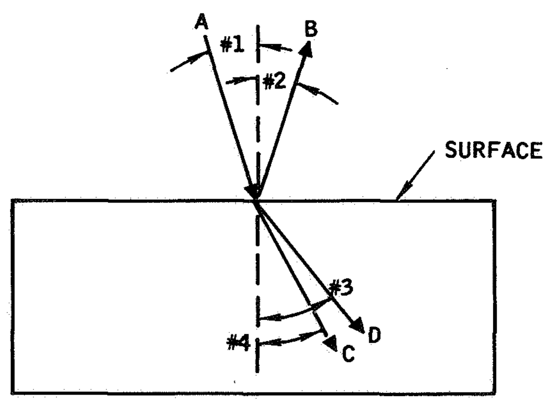
47. The adjacent figure illustrates four waves. Wave A strikes the surface of the specimen and produces waves B, C, and D. The reflection angle is ________.

a. #1
b. #2
c. #3
d. #4



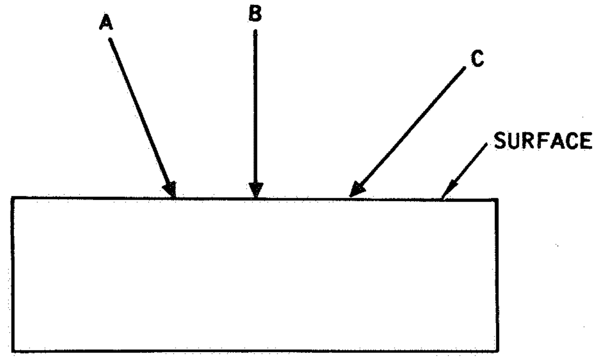
48. The adjacent figure illustrates four waves. Wave A strikes the surface of the specimen and produces waves B, C, and D. The refraction angles are ________.

a. #1
b. #2
c. #3
d. #4



49. The adjacent figure illustrates three waves striking a surface. The wave that is normal to the surface is ________ .

a. A
b. B
c. C



50. The movement of sound waves through a medium is usually referred to as wave propagation. (True - False) ________________

51. Ultrasonic waves transmitted in fluids such as water are usually ________________ ________________.

a. Lamb waves
b. Rayleigh waves
c. Shear waves
d. Longitudinal waves

52. The surface between two media is called an ________________ .

53. A beam of energy approaching an interface is called the ________________ beam or wave.

54. The angle at which a wave or beam of energy strikes a surface in relation to an imaginary line drawn perpendicular to the surface is called the angle of ________________.

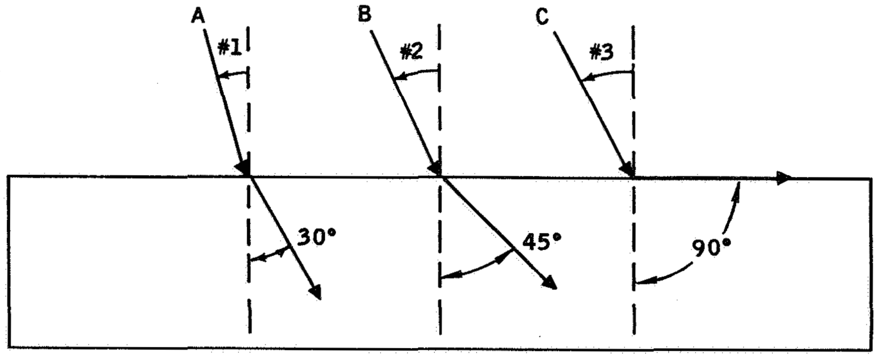
55. When an incident beam strikes an interface between two different media at other than normal incidence, part of the incident beam will be converted into other modes of vibration. (True - False) ________________

56. The bending of a sound beam as it passes through an interface is called ________________.

a. Reflection
b. Refraction
c. Attenuation
d. Absorption

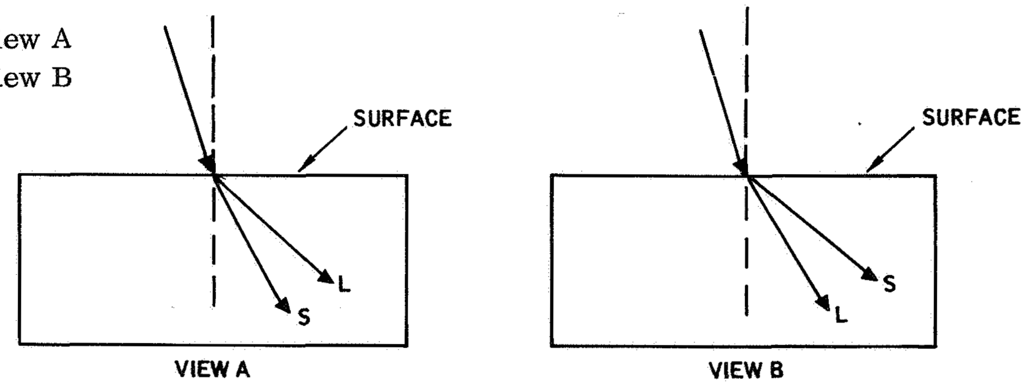
57. The adjacent figure shows a wave applied to a specimen at three different incident angles (#1, #2, and #3) with the corresponding refraction angles (30°, 45°, and 90°). The critical angle is_______________.

a. #1
b. #2
c. #3



58. The adjacent two views show a longitudinal wave striking the surface of a specimen at an angle. This wave is converted into both longitudinal (L) and shear (S) waves within the specimen. Which of the views shows the proper relationship between the L and S waves within the specimen?_______________.

a. View A
b. View B



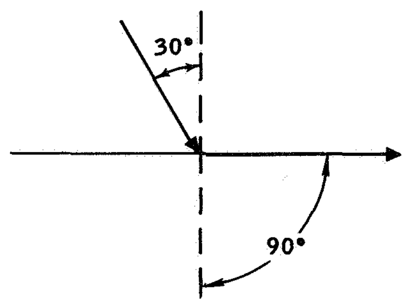
59. When the angle of incidence for a longitudinal wave exceeds the critical angle, the____.

a. Longitudinal wave mode will be at its maximum amplitude in the specimen
b. Longitudinal wave mode will be totally reflected
c. Shear wave mode will be totally reflected
d. Longitudinal wave mode only will be transmitted into the specimen

60. The adjacent figure shows a sound beam applied to a specimen at an angle that causes the shear wave mode to refract 90 degrees. Under this condition, a new wave is developed. This new wave is called a (Choose two)

__________________________ __________________________

a. Surface wave
b. Rayleigh wave
c. Lamb wave
d. Plate wave
e. Transitional wave



61. When the angle of incidence for shear waves exceeds the critical angle, we have____.

a. Only the surface wave mode entering the specimen
b. Maximum amplitude of the shear wave mode entering the specimen
c. Only the longitudinal wave mode entering the specimen
d. Total reflection of both longitudinal and shear wave modes

62. Surface waves travel on the surface of a specimen with a velocity____.

a. Twice that of shear waves and will be dampened out by any object or material placed in their path
b. Half that of shear waves and are dampened out by liquids or your finger placed in their path
c. Slightly less than that of shear waves with particle motion following an elliptical orbit
d. Slightly less than that of shear waves with particle motion in the same direction as wave travel

63. Surface waves are rapidly dampened out by grease, water, or any other material placed on the surface of the test specimen. (True - False)__________.

64. Ultrasonic waves which propagate through thin sheet or plate material and have a very complex particle motion in the form of elliptical orbits are called (choose two) ____________________ ____________________.

a. Plate waves
b. Rayleigh waves
c. Lamb waves
d. Transitional waves

65. The velocity of longitudinal, shear, and surface waves depends only on the material through which they are propagating, while plate waves depend on the frequency, incidence angle, material, and material thickness. (True - False) ________________

66. Two basic types of plate waves exist. These are the ______________________ ____________________.

   a. Symmetrical and delational
   b. Symmetrical and asymmetrical
   c. Asymmetrical and irrotational
   d. Perpendicular and normal

67. What type waves are used to excite resonance within a specimen? ______________

   a. Pulsed longitudinal waves
   b. Pulsed shear waves
   c. Continuous longitudinal waves
   d. Continuous shear waves

68. Resonance occurs when material thickness is equal to a full wavelength or exact multiples thereof. (True - False) ________________

69. The fundamental resonant frequency is the minimum frequency at which a given material will resonate. (True - False) ________________

70. The formula used to determine the fundamental resonant frequency is __________.

   a. $F = \frac{V}{T}$
   b. $F = \frac{V}{2T}$
   c. $F = \frac{T}{V}$
   d. $F = VT$

71. Whole number multiples of a fundamental resonant frequency are called ________________.

   a. Phonics
   b. Half waves
   c. Harmonics
   d. Resonant waves

72. Which of the following best describes the relationship of resonance amplitude to increasing harmonics? ______________________

   a. Increases
   b. Varies
   c. Decreases
   d. Remains the same

73. The frequency difference between two adjacent harmonics equals the ______________________.

a. Maximum resonant frequency
b. Fundamental resonant frequency
c. Residual frequency
d. Wavelength

74. The test system which relies on reflected energy to find discontinuities is called the______________________.

a. Through transmission system
b. Pulse-echo system
c. Resonance system
d. Reflection system

75. With through transmission, a decrease in indication amplitude (height) denotes the presence of a discontinuity. (True - False) ____________

76. The through transmission system is the best system for determining the depth of discontinuity. (True - False) ____________

77. The resonance system can be used to (choose two) ______________________.

a. Find small discontinuities
b. Find relatively large discontinuities
c. Measure material thicknesses
d. Find multiple discontinuities at several different depths in a specimen

78. The pulse-echo system usually uses the same transducer for both transmitting and receiving of ultrasonic waves. (True - False)____________

79. The through transmission system uses______________________.

a. The same transducer for transmitting and receiving ultrasonic energy
b. Separate transducers for transmitting and receiving ultrasonic energy
c. Separate transducers transmitting continuous ultrasonic waves
d. A single transducer transmitting continuous ultrasonic waves

80. Only continuous waves are transmitted by the pulse-echo system. (True - False) ____________

81. Most resonance systems use ______________________________.

a. A single transducer transmitting continuous waves
b. A single transducer transmitting pulsed waves
c. Separate transducers transmitting pulsed waves
d. Separate transducers transmitting continuous waves

82. In the through transmission system, the transmitting and receiving transducers must be geometrically aligned with one another and the soundness of a material is measured in terms of energy loss. (True - False) ____________

83. Standing waves are set up within a specimen when using the ______________________.

a. Pulse-echo system
b. Through transmission system
c. Resonance system

84. The resonance system relies on changes in resonant frequency to find discontinuities. (True - False) ____________

85. The test methods used in ultrasonic testing are (Choose two) ______________________

a. Submerged testing
b. Contact testing
c. Surface testing
d. Immersion testing

86. In an A-scan presentation, the horizontal sweep represents ______________________.

a. Elapsed time or distance
b. Signal amplitude
c. Distance traveled by the transducer
d. Direction of wave travel

87. In the A-scan presentation, the vertical deflection on the cathode-ray tube represents ______________________.

a. Elapsed time or distance
b. Signal amplitude
c. Distance traveled by the transducer
d. Direction of wave travel

88. In an A-scan presentation, the initial pulse is the ______________________________ ______________________________.

a. High indication on the extreme left side of the CRT screen and represents the front surface of the specimen
b. Indication or "pip" that suddenly appears during scanning and represents the first discontinuity indication
c. First pulse that appears on the right side of the CRT screen and represents the back surface of the specimen
d. First pulse that appears on the left side of the CRT screen and represents the back surface of the specimen

89. In the A-scan presentation, "pip" height is an indication of ______________________________ ______________________________.

a. The amount of energy reflected by an interface
b. The distance between the discontinuity and the surface of the material
c. The type of waves used
d. The wavelength of the ultrasonic beam

90. The B-scan presentation essentially shows ______________________________.

a. Resonant frequency distributions in a test specimen
b. Grain size of the test specimen
c. Cross-sectional view of the test specimen
d. Amplitude of reflections from the specimen

91. The C-scan presentation shows ______________________________.

a. Depth of a discontinuity
b. Thickness of a specimen
c. Thickness of a discontinuity
d. Internal plan view of the specimen

92. In contact testing, the transducer physically touches the specimen and is coupled to the specimen through a thin film of couplant. (True - False) ______________

93. In immersion testing, only the test specimen is immersed in the couplant. (True - False) ______________

94. Square wave markers are sometimes used in the A-scan presentation to ______________ ______________________________.

a. Show signal amplitude
b. Estimate discontinuity size
c. Denote units of time or distance
d. Measure the distance traveled by the transducer

95. The A-scan presentation is a CRT screen display showing existence, position, and approximate size of discontinuities. (True - False) ____________________

96. The dead zone is that area of a specimen which lies directly beneath the transducer, from which no indications can be received because of the inherent length of the initial pulse. (True - False) ____________________

97. The surface condition (roughness) of a specimen has little effect on the transmission and receiving of ultrasonic energy. (True - False) ________________

98. The lack of parallelism between the front and back surfaces of a specimen ______ ____.

a. Makes it difficult to locate discontinuities that lie parallel to the front surface
b. May result in a CRT display that does not contain a back surface indication
c. Usually results in a CRT display having multiple indications of irregular amplitude
d. Will decrease ultrasonic wave penetration

99. Which of the following will not produce spurious indication? ________________ .

a. Mode conversion
b. Attenuation
c. Beam spread
d. Refraction

100. Coarse grain materials will produce indications having ________________________ ______________________________.

a. Less amplitude (height) than fine grain materials
b. Greater amplitude than fine grain materials
c. The same amplitude as fine grain materials
d. No amplitude

101. The ideal surface condition for ultrasonic testing is ______________________.

a. A rough surface
b. A contoured surface
c. An irregular or polished surface
d. A flat smooth surface

102. A specimen having coarse grain structure or excessive fine porosity appears on the CRT screen as ____.

a. A broad-based front surface indication of reduced amplitude
b. Multiple indications of irregular amplitude
c. Peaked front and back surface indications
d. Multiple indications of constant amplitude

103. A specimen having a fine grain structure appears on the CRT screen as ____.

a. Broad-based indications of constant amplitude
b. Multiple indications of irregular amplitude
c. Peaked front and back surface indications
d. Multiple indications of constant amplitude

104. Spurious indications may result if an ultrasonic beam spreads to the sides of a specimen before reaching the back surface. (True - False) ____________

105. A discontinuity lying at an angle to the specimen's front surface will reflect at an angle which could miss the transducer and not be detected. (True - False ____________.

106. The amplitude of a discontinuity having a smooth surface will be ____.

a. Greater than a rough surface discontinuity
b. Less than a rough surface discontinuity
c. The same as a rough surface discontinuity
d. Dependent on the back surface indication

107. Discontinuities oriented at extreme angles to the specimen front surface can be detected using (Choose two) ____.

a. Contact method and straight beam transducer
b. Contact method and angle beam transducer
c. Contact or immersion method and curved beam transducer
d. Immersion method and straight beam transducer

108. Nonmetallic inclusions produce reflections having greater amplitude than similar size cracks or voids. (True - False) ____________

109. The amplitude for a given size discontinuity will vary according to its location in the specimen. (True - False) ____________

ANSWERS FOR SELF-TEST

		Page No. Ref.			Page No. Ref.
1.	true	1-9	27.	a	2-9
2.	c	1-13	28.	false	2-15
3.	c	1-4	29.	a	2-26
4.	a	1-15	30.	d	2-15
5.	b	1-15	31.	a	2-17
6.	d	1-5	32.	b	2-17
7.	false	1-4	33.	false	2-19
8.	d	1-13	34.	d	2-22
9.	true	1-9	35.	d	2-22
10.	true	3-1	36.	a	2-24
11.	b	1-23	37.	false	2-26
12.	true	1-40	38.	c	2-21
13.	b	1-23	39.	c	2-22
14.	true	1-33	40.	true	2-27
15.	d	1-37	41.	b	3-23
16.	b	1-47	42.	d	3-23
17.	b	1-42	43.	a	3-13
18.	b	2-3	44.	a	3-15
19.	d	2-27	45.	a	3-17
20.	a	1-50	46.	a	3-9
21.	a	1-50	47.	b	3-13
22.	c	2-1	48.	c and d	3-21
23.	false	2-10	49.	b	3-11
24.	a	2-12	50.	true	3-2
25.	a	2-12	51.	d	3-15
26.	b	2-12	52.	interface	3-6

Review page reference on questions that you miss.

ANSWERS FOR SELF-TEST (Continued)

		Page No. Ref.			Page No. Ref.
53.	incident	3-9	79.	b	5-4
54.	incidence	3-9	80.	false	5-2
55.	true	3-18	81.	a	5-5
56.	b	3-21	82.	true	5-4
57.	c	3-26	83.	c	5-5
58.	a	3-21	84.	true	5-5
59.	b	3-26	85.	b and d	5-7
60.	a and b	3-29	86.	a	5-18
61.	d	3-28	87.	b	5-21
62.	c	3-29	88.	a	5-18
63.	true	3-29	89.	a	5-21
64.	a and c	3-30	90.	c	5-15
65.	true	3-30	91.	d	5-17
66.	b	3-30	92.	true	5-7
67.	c	4-1	93.	false	5-9
68.	false	4-3	94.	c	5-25
69.	true	4-7	95.	true	5-13
70	b	4-7	96.	true	5-26
71.	c	4-5	97.	false	6-1
72.	c	4-14	98.	b	6-3
73.	b	4-14	99.	b	6-7
74.	b	5-2	100.	a	6-13
75.	true	5-4	101.	d	6-1
76.	false	5-2	102.	b	6-13
77.	b and c	5-5	103.	c	6-13
78.	true	5-2	104.	true	6-10

Review page reference on questions that you miss.

ANSWERS FOR SELF-TEST (Continued)

		Page No. Ref.
105.	true	6-17
106.	a	6-22
107.	b and d	6-19
108.	false	6-25
109.	true	6-27

Review page reference on questions that you miss.